THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS™

SCIENCE | ENVIRONMENT | TECHNOLOGY | TRANSPORT | HISTORY | SPACE

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JAGUARS
HOW THIS JUNGLE PREDATOR SURVIVES

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FIRESTORMS
Huge wildfires that can create their own weather

HUMAN NECK
What makes this part of the body so flexible?

HOW IT WORKS

ISSUE 46

WELCOME

The magazine that feeds minds!

Get in touch

Have YOU got a question you want answered by the How It Works team? Get in touch via:

- HowItWorksMagazine
- howitworks@imagine-publishing.co.uk
- www.howitworksdaily.com
- @HowItWorksmag

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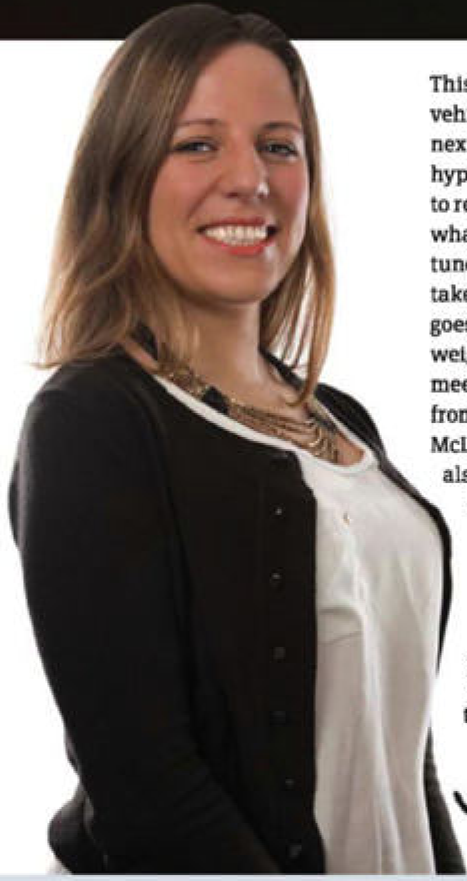
Explore a rainforest habitat from top to bottom and meet some of the colourful critters that call it home



This issue we explore the physics-defying vehicles taking speed and performance to the next level in our cover feature on how next-gen hypercars are being designed and engineered to reach blistering speeds. We explain not just what powers the amazing engines and finely tuned components under the hood, but also take a look at all the other cool science that goes into consideration. Discover the effects of weight, drag, aerodynamics and more as we meet some of the latest monsters to emerge from world-class production lines like those of McLaren, Porsche, Ferrari and Koenigsegg. We also reveal the genius involved in making the DeltaWing, a relatively low-powered car that can take advantage of physics to hit speeds in excess of 300 kilometres (186 miles) per hour – and looks like the Batmobile to boot! By the end you'll appreciate that as well as being hyper-fast, hyper-powerful and hyper-expensive, all these vehicles are also hyper-cool. Enjoy!

Helen

Helen Porter
Editor

What's in store...

The huge amount of information in each issue of How It Works is organised into these key sections:

Science
Uncover the world's most amazing physics, chemistry and biology

Technology
Discover the inner workings of cool gadgets and engineering marvels

Transport
Everything from the fastest cars to the most advanced aircraft

Space
Learn about all things cosmic in the section that's truly out of this world

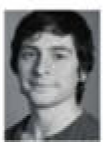
Environment
Explore the amazing natural wonders to be found on planet Earth

History
Step back in time and find out how things used to work in the past

Meet the team...

Robert
Features Editor
If you only check out one thing this issue, bask in the glory of the U-boat cutaway – the detail is unbelievable.

Helen
Senior Art Editor
I've loved learning about the incredible technology that goes into keeping mega-structures safe.



Ben
Features Editor
Talking to Alan Rabinowitz about jaguar corridors and big cat conservation was the highlight of the issue for me.

Adam
Senior Sub Editor
I've always wondered how printers can make 3D objects, and now I know how they do it – layer by layer.

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The magazine that feeds minds!

MEET THE EXPERTS

Find out more about the writers in this month's edition of **How It Works...**

Lee Sibley
Hypercars

Motorhead Lee edits the Porsche magazine **Total 911** and with his contagious enthusiasm for anything automotive we went straight to him for the **How It Works** hypercars feature.

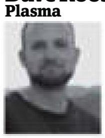
Alexandra Cheung
Toxic science

This issue Alex 'carefully' gets you closer to the complex science of toxins, revealing just what makes them so deadly to the human body as well as how and where they occur around the globe.

Aneel Bhangu
The neck

Surgeon Aneel explains the physiology of the human neck. A lot goes on between the head and the torso, including arteries, veins, the spinal cord and a whole lot more essential anatomy.

Dave Roos
Plasma



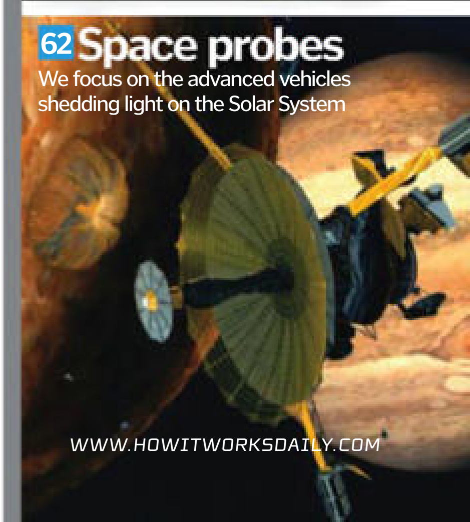
This issue science buff Dave reveals why superheating gas ionises atoms so they glow. Everyday examples of plasma – the 'forgotten' state of matter – include the welding torch and even lightning.

Michael Scott
Rainforest layers

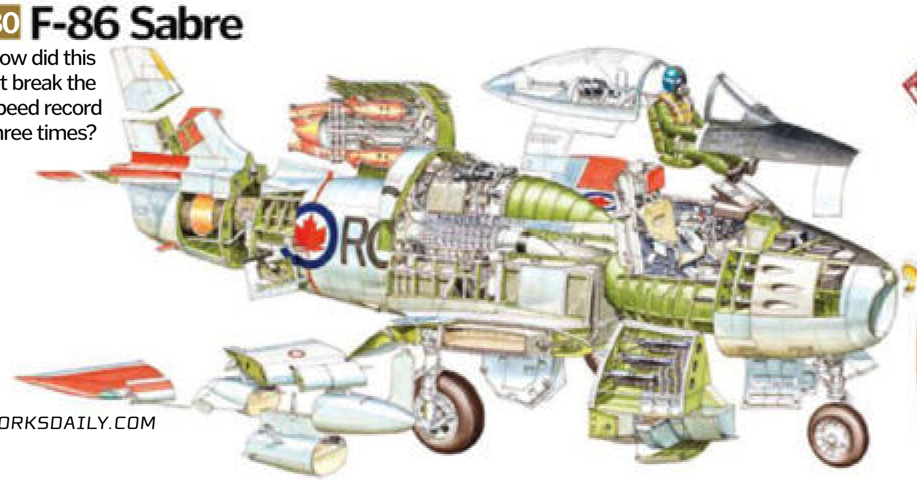
This issue botanist, writer and broadcaster Michael examines the diverse flora and fauna of the rainforest. He has earned an OBE for his services to biodiversity conservation in Scotland.

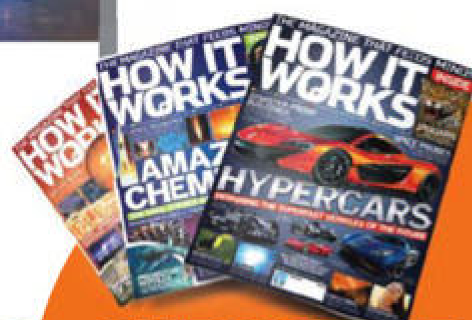
What's inside the BlackBerry Z10? Find out on page 47

"Today's hypercars are lighter, faster, cleaner, safer and more efficient than ever before"



REGULARS





Ancient galaxy making stars at record rate

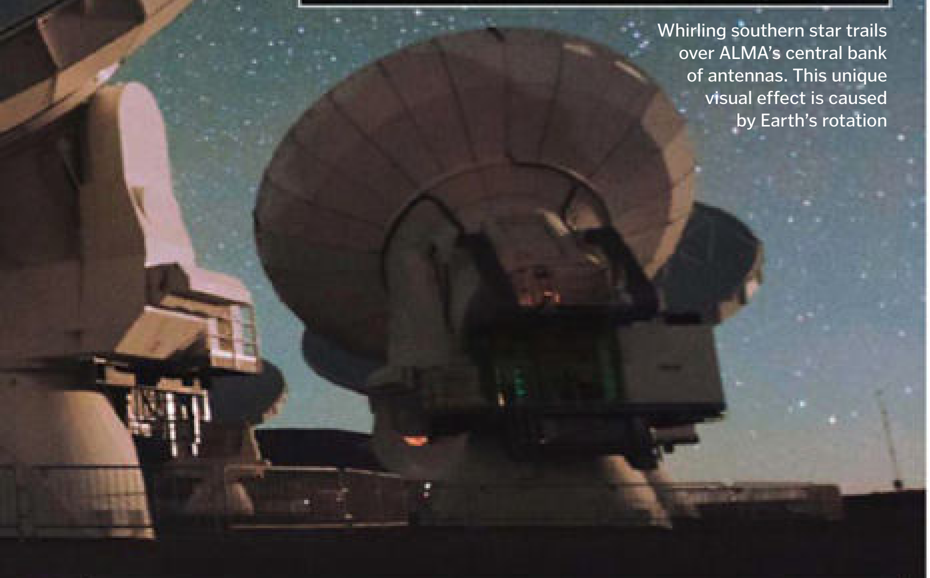
Discovery by the £1bn ALMA telescope array rewrites the rules on star birth

Following a recent inauguration ceremony, the ALMA (Atacama Large Millimeter/sub-millimeter Array) observatory in Chile's Atacama Desert has imaged an ancient distant galaxy making stars at a furious rate. The galaxy, which was imaged by ALMA's antenna array, was discovered using a technique referred to as gravitational lensing, observing an object's light as it bends around a nearer massive body or galaxy.

The ancient galaxy has been observed producing stars at a rate of up to 1,000 per year, which contrasts markedly with the Milky Way, which sees on average just one new star born annually. The most important aspect of the discovery of this 'star burst' though is the dating, which according to data generated at ALMA is approximately 12 billion years ago – just 1.7 billion years after the theorised Big Bang. If this is confirmed, then astrophysicists will have to re-evaluate the official timeframe for star bursts to have occurred in.

Speaking on the remarkable images of the ancient, star-generating galaxy, Carlos De Breuck of the European Southern Observatory (ESO) said: "Only a few gravitationally lensed galaxies have been found before at these submillimetre wavelengths, but now ALMA's found dozens of them. This kind of science was previously done mostly at visible-light wavelengths with the Hubble Space Telescope, but this shows that ALMA is a very powerful new player in the field."

Indeed, the prospects for ALMA are very exciting, especially considering that the recent discovery was made by employing only 16 of the array of 66 antennas. When all 66 are combined, astronomers will be able to image even more distant and ancient galaxies at high speed. Speaking on ALMA's potential for the future, ALMA team member Axel Weiss said: "ALMA's sensitivity and wide wavelength range mean we could make our measurements in a few minutes per galaxy – about 100 times faster than previous telescopes."

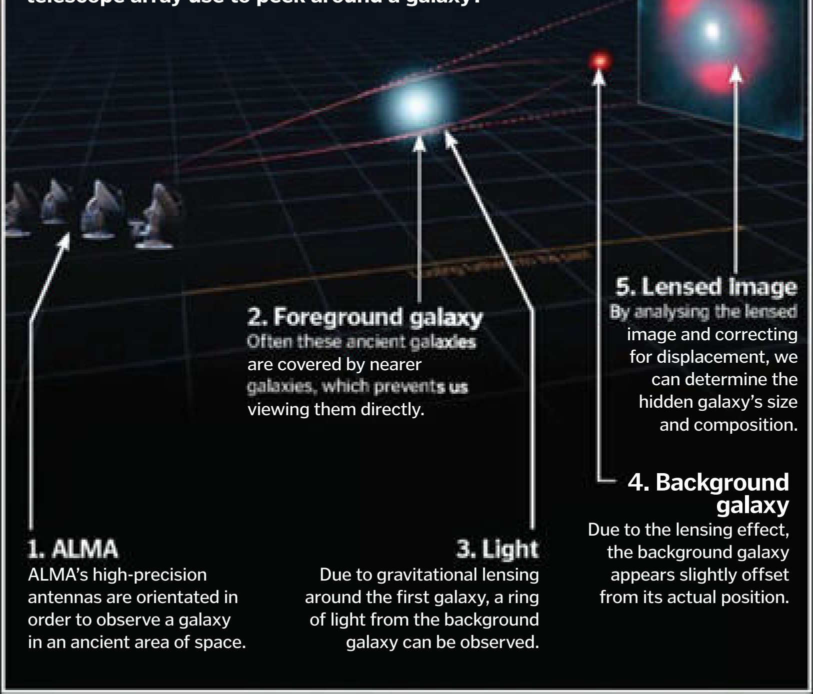


"The ancient galaxy has been observed producing stars at a rate of up to 1,000 per year"

Whirling southern star trails over ALMA's central bank of antennas. This unique visual effect is caused by Earth's rotation

How does ALMA see so far?

What clever techniques does this terrestrial telescope array use to peek around a galaxy?



Galaxy S4 pioneers new phone tech

Next-gen superphone dubbed the 'iPhone killer' is unveiled

Samsung has announced its much-anticipated new flagship smartphone, the Galaxy S4. The phone, which continues the company's Galaxy series, comes with a selection of hardware improvements over its predecessor, as well as a new suite of software.

Chief among these features are Air Gesture, which allows users to navigate the phone without even touching the screen, and Air View, which lets you preview images, videos and emails by hovering your finger over them. Smart Scroll enables text to be moved through by tilting the device up or down and Smart Pause means videos can be automatically paused when a user looks away from the screen then restarted when they look back.

In terms of hardware, the real talking point is the up-rating of the device's HD Super AMOLED panel to 441 pixels per inch in a 12.7-centimetre (five-inch) display. It has also been reduced in thickness and weight, down to 7.9 millimetres (0.3 inches) and 130 grams (4.5 ounces), respectively.

"Air Gesture allows users to navigate without even touching the screen"

BSA appoints new CEO

From 2 April 2013, the British Science Association (BSA) is to be overseen by Oxford-trained scholar Imran Khan. Khan, who has developed a sterling reputation in the scientific field as both a respected academic and expert communicator, is to lead the development of the BSA over the coming years and take a hands-on approach in making science as accessible as possible to members of the public. Speaking on his appointment, Khan said: "I'm delighted to be joining the British Science Association at such an exciting time. Science is a bigger part of our lives than ever before, and promoting understanding between scientists and the public has therefore never been more important." One of Khan's first major tasks as CEO will be overseeing the now world-famous British Science Festival. This year's festival is taking place in Newcastle, England, between 7-12 September. For more information about the event, you can visit: **www.britishscienceassociation.org**.

Big cats on the brink

Famed for his love of tigers and jaguars, Panthera CEO Alan Rabinowitz tells How It Works about the challenges and the dangers of wild cat conservation

You're best known for your work with big cats. What draws you to them?
My first real affinity for big cats came because, as a child, I had a severe stuttering problem and my father would take me to Bronx Zoo. I would stand in front of the old jaguar and sometimes the tiger and I would talk to them, because I could talk to animals, but I couldn't speak normally to people. I felt these big cats were so powerful yet they were locked up in these cages despite their strength.

I've always sought to give wildlife a voice – to save some of the last big wild areas. The big cats represent one of the best opportunities to do that because they're apex predators.

On the human side, they open up doors; they strike emotions in people. No government I've ever met – despite how poor the country is – ever said they want to lose all their big cats.

On the ground, we don't have the time to study every single species and its place in the ecosystem. Although my real desire is to save large wild areas, the way to do that is to save the apex predators, which can only survive if all the other components of the system are intact and healthy. That's the big cats. If things fail lower down, then the apex predators can't survive.

So what role do these apex predators play in their respective environments?
Would the world really be worse off if we lost jaguars or tigers? Without a doubt, yes. These apex predators play a pivotal role in the balance of the ecosystem. How can we most easily see that? The world is seeing it very clearly now with this whole spate of emerging infectious diseases, like SARS, West Nile Virus, Ebola… things which are not new. They've been in the system on our planet for a very long time. But the firewall that has helped keep most of these diseases in check has been the natural environment. Now when you take away apex predators, that completely throws out the balance of the environment. Everything below that, you get what's called ecological release – an explosion of species that can be carriers or can help to spread the diseases themselves.

How important is educating people about these environmental issues to Panthera's general conservation efforts?
Well, it is and it isn't. I have to tell you, quite honestly, that we don't have an education programme where we go out to try to educate school children about why tigers are important. The reason is because Panthera was set up to occupy a niche not occupied previously: that's to go out with a fine-tuned focus to address the most critical threats – immediately – that are facing big cats in the wild today.

Now, for that to be sustainable long term, you will need an educated public. But we can't wait for that – we've got to stop the 'bleeding'; I always call it that because these big cat species are akin to a gunshot patient that's being wheeled into the emergency room having taken several bullets in the chest. We simply don't have the time to educate the person's family or the patient themselves on how they should change their lives to avoid this happening again. [We have to act now.]

Many wild cats are found in countries with strained political and/or economic situations. How do you deal with this?
China's our biggest challenge, to put it mildly. Part of the problem has been the tiger trade. We're not standing as Westerners saying, "This is wrong, you shouldn't be doing these things. You could be taking aspirin instead of rhino horn for a fever, ibuprofen instead of tiger bone for pain relief." That's not the way to get at it.

Then the Chinese say, "Look. You want to keep tigers alive and we find tigers have a value, medicinally. Let us breed them in captivity and just use bred tigers for medicine." Now the tiger world jumps up in arms and shouts, "You can't breed tigers for that!" I have to tell you, that's a non-argument. No one wants to see animals raised to be killed – especially a spectacular and iconic species like the tiger. But the fact is that, if somebody could actually show me a clear way to save tigers in the wild through an alternative means, then I might be open to listening to that.

That's the way to approach China: [with an open mind]. We do work with the Chinese and there are many high-level officials who want to do the right thing and save the tiger. But that country is not easily controlled on all levels. When you're talking indigenous groups killing

Rabinowitz helps to collar a young adult jaguar in Belize so its movements can be tracked to inform Panthera's conservation work in the region

"I would stand in front of the old jaguar and sometimes the tiger and I would talk to them, because I could talk to animals, but I couldn't speak normally to people"

and trading in tiger parts across the Burmese-Chinese border, for instance, that's not easily regulated by the government in Beijing.

Your work in Belize and Burma has put you in the middle of some politically factious situations. Have you ever felt threatened?
I've never felt in danger from the wildlife, that's for sure! Now there have been some touchy instances – one in Central America and a couple in Burma where the local people didn't believe who I was. If you're a local out in the middle of nowhere, why would you believe some American is just out there to count tigers, versus looking at where you're growing opium or marijuana, etc? The time I felt in most danger was actually when the government has tried to protect me; when they insist I go into an area with soldiers, which happened several times in Burma. So I was surrounded by soldiers with guns and I felt more threatened there, in terms of being caught up in crossfire, than I did when I was allowed to go into these areas by myself.

Tell us about Panthera's jaguar and tiger corridors. Why is it so crucial to maintain long strips of territory for these species?
These are the most important endeavours I've ever done. Some of the big causes of extinction are isolation, fragmentation, small population size and too few individuals breeding with one another. So you always want to avoid this. But these jaguars were doing something that none of us thought they could: moving outside of their protected areas through the human landscape. These corridors where the jaguars were passing through included rubber plantations, citrus groves, ranches and even people's backyards. They're moving through this terrain to get to the next protected zone.

You only need a few to make it through these corridors to the next area to maintain genetic viability. Why is that so important? Once you've created that link from one population to the next, what you essentially have is an ecological population that's the same as if they were one. If there's genetic movement between these [groups then] you have a huge population that has a much, much greater chance of surviving than any individual fragment.

It's something we never thought we could get at because no country wants to make huge conservation areas. But the jaguar figured this out for us; I just had to work out where those corridors were, then work with governments with land-use zoning plans to keep them intact.

This is no sweat off a government's back; they can claim to be more green and yet do nothing new. And the locals love it as it gives them more rights to their land. When I've told people they're living in a jaguar corridor, they tell me, "You're crazy! We haven't had jaguars here for 50 years!" I reply, "Well, you don't have jaguars living *around* you, but I can show you pictures of them, I can show you tracks." They're often very shocked. This is perfect, as it makes them realise that these corridors are no threat.

You can read more about Alan Rabinowitz and his work with big cats on the Panthera website: www.panthera.org. To learn more about jaguars in particular, head to page 32.

10 COOL THINGS WE LEARNED THIS MONTH

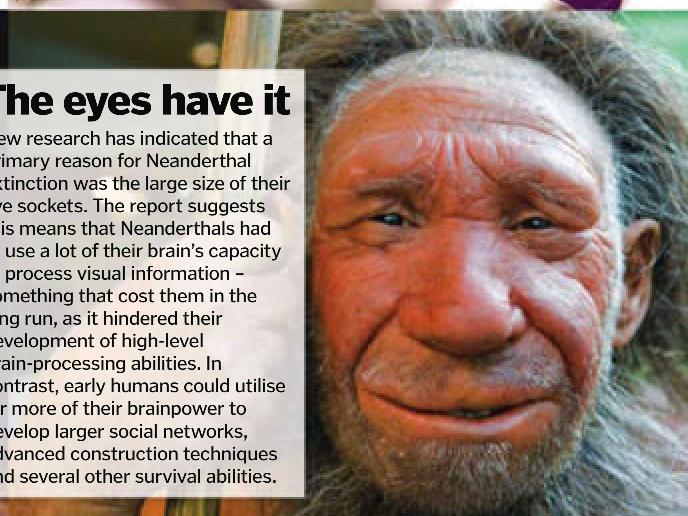
FACTS YOU ALL SHOULD KNOW

Crocodiles now come in miniature

This is the Mandarin salamander, whose back ridges and body shape have earned it the nickname 'crocodile newt'. A new species from this same family has recently been found in Vietnam with an even more striking resemblance to the ferocious reptile, on a miniature scale. The new salamander – Tylototriton ziegleri – has been called Ziegler's crocodile newt, after researcher and conservationist, Thomas Ziegler.

Orchids ape monkeys

This little fella is actually the flower of a species of orchid called Orchis simia – or more commonly the monkey orchid. They're found on a number of continents and smell rather like faeces (yuck). Dracula simia blooms, on the other hand, look remarkably like monkey faces with fang-like sepals, and smell of ripe oranges.

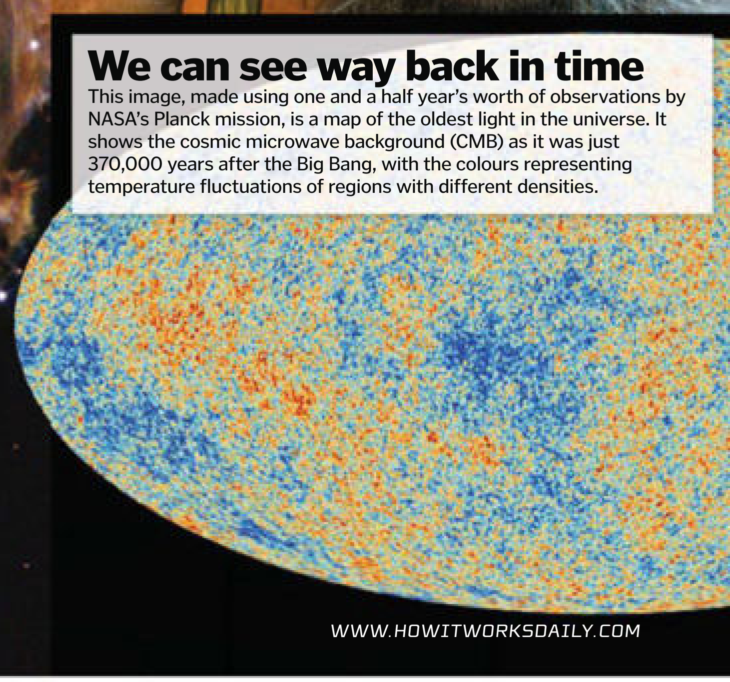


The eyes have it

New research has indicated that a primary reason for Neanderthal extinction was the large size of their eye sockets. The report suggests this means that Neanderthals had to use a lot of their brain's capacity to process visual information – something that cost them in the long run, as it hindered their development of high-level brain-processing abilities. In contrast, early humans could utilise far more of their brainpower to develop larger social networks, advanced construction techniques and several other survival abilities.

Light can 'echo'

Just like sound, light can 'echo' by reflecting off distant objects, although you need a cosmic scale to witness it. That's exactly what we got with the star V838 Mon, which inexplicably flashed to briefly become the brightest star in the Milky Way in 2002. The halo you see in this image isn't expelled material from V838 Mon, but the light from the flash visibly rebounding off dust in a span of around six light years in diameter.



We can see way back in time

This image, made using one and a half year's worth of observations by NASA's Planck mission, is a map of the oldest light in the universe. It shows the cosmic microwave background (CMB) as it was just 370,000 years after the Big Bang, with the colours representing temperature fluctuations of regions with different densities.

The solar maximum is oddly minimal

2013 is supposed to be a solar maximum – a time when the Sun is at the peak of its 11-year cycle and as many as 200 sunspots are visible at its surface. Yet this image, taken at the end of February, shows a clear surface with the exception of one or two spots. It's possible that the Sun is experiencing a dip between a double-peak in its solar maximum, as 2011 featured a lot of solar activity.

Cockerels have built-in clocks

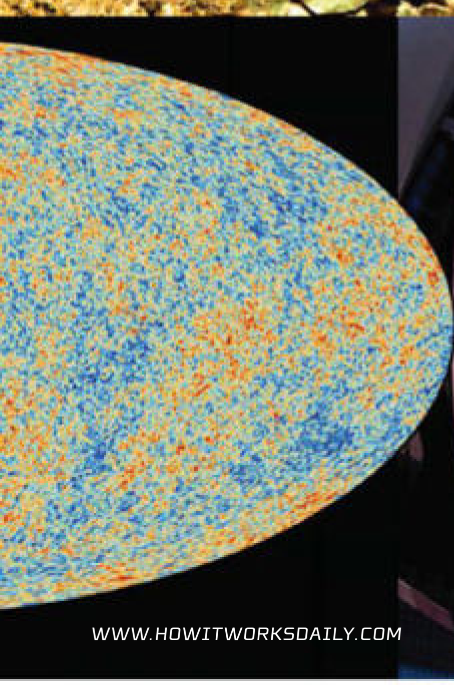
According to scientists in Japan, cockerels don't crow at the break of daylight each morning, but instead a highly intricate circadian rhythm dictates when the bird lets rip. This discovery was made when a group of roosters were put in a soundproofed, windowless room and subjected to 24 hours of artificial lighting. Despite the continuous light, the roosters began crowing just before dawn the following morning, despite being unable to see the Sun rising.

Earthquakes sometimes have a 'golden lining'

A new study published in *Nature Geoscience* has revealed that the fluctuating pressure in underground fissures caused by earthquakes could be responsible for up to 80 per cent of our planet's gold deposits. The precious metal is left behind when a sudden drop in pressure causes the water it's dissolved in to suddenly vaporise. This explains why much of the world's gold formed around 3 billion years ago in a period of extensive tectonic activity.

Some metal melts on contact

Gallium is a soft metal commonly used for electronics, with over 98 per cent of world production used in semiconductors. It also has an unusually low melting point of just over 29.7 degrees Celsius (85.5 degrees Fahrenheit), so if you hold it in the palm of your hand (which is typically around 37 degrees Celsius/98.6 degrees Fahrenheit) for long enough, it will turn to liquid!



New radar can spot tennis balls

The aerospace and defence manufacturer BAE Systems has created a radar system that can detect a tennis ball-sized object travelling at three times the speed of sound from over 24 kilometres (15 miles) away. Called the Artisan system, it is being installed on HMS Iron Duke among other Type 23 ships in the British fleet.

NEXT-GEN HYPERCARS

Just when you thought the world's fastest cars had reached the pinnacle of motoring physics, a new generation is set to break the boundaries once more…

RECORD BREAKERS
VEYRON VROOM

431.07km/h

FASTEST PRODUCTION CAR

In 2010, the Bugatti Veyron 16.4 Super Sport achieved a top speed of over 431 kilometres (268 miles) per hour at the Volkswagen test track in Ehra-Lessien, Germany.

DID YOU KNOW? Tyre pressure is much higher in hypercars to help counter rolling resistance

Today's hypercars are faster, lighter, safer, cleaner and more efficient than ever before, as they push physics to the limit to deliver the ultimate thrill behind the wheel.

The first car in the world to hit 322 kilometres (200 miles) per hour was a purpose-built land speed machine driven by Sir Henry Segrave at Daytona Beach, FL, in 1927. Now, everyday road-going hypercars reach that figure with ease, and some go way above that. The Bugatti Veyron set the tone some eight years ago, when it was (for a time) the fastest production car on Earth with a hefty 736 kilowatts (1,000 brake horsepower) helping to produce a jaw-dropping top speed of 408 kilometres (253 miles) per hour.

Not only are these top-end road machines reaching unprecedented speeds, they're also reaching them in less time too. In early-2013, the Hennessey Venom GT broke the record for the quickest dash to 300 kilometres (186 miles) per hour, taking just 13.63 seconds to do so.

A glut of ultra-lightweight chassis and body panels are now used to help keep the overall weight of these cars at large to a minimum, greatly increasing a car's power-to-weight ratio – essential for extracting maximum power.

For hypercars to reach these unworldly speeds, it's not all about sheer power and weight ratios though. Hypercars need to be low to the ground for maximum traction, as poor grip makes for bad handling and, more importantly, no acceleration. They also need to be very aerodynamic with as little drag on the body as possible, to enable the car to slip through the air with minimal resistance.

For this reason most hypercars now use active aerodynamics to reach such crazy figures, with the bodywork and even chassis automatically adjusting to best manage the flow of air and pressures on the car when travelling at certain speeds.

Mechanical efficiency has also vastly improved in the quest for high speed, with some engines now enjoying much higher rev limits in which to exert their power, while dual-clutch gearboxes pre-select the next gear to ensure only a minuscule amount of acceleration time is lost to gear changing.

However, there are still obstacles to overcome. Great evolutions in technology, such as Porsche's active rear wheel steering (which changes the direction of the rear axle by a few millimetres to allow corners to be taken more directly and at greater speed) only provide tiny improvements to 0-60 times and top speeds.

Similarly, while cars are being stripped of every non-essential element, with all remaining parts made from extremely light composites, car scientists are already having to 'weigh up' just how much they can take away without being detrimental to performance. Indeed, finding that next step to go even faster may take a new technology altogether, rather than tweaks to current components.

Another important obstacle is an environmental one. Our planet will run dry of a car enthusiast's favourite liquid in the not-too-distant future, and with hypercars famed for guzzling up gallons of precious fuel on every journey, the lifestyle needs to change.

Already, three 322-kilometre (200-mile)-per-hour cars released this year now deploy hybrid engines to bring down their fuel consumption and carbon footprint, and even Formula One cars will have hybrid engines from next year where the electric motor will be fully engaged the moment the car enters the pit lane. It's certainly a good start, but when fuel does run out, we'll need hypercars that run on zero fuel, or all the technology to date will go to waste.

The world of the hypercar then has never been more advanced, and here's how some of the market's leading hypercar companies are doing all they can to go that extra mile...

“McLaren has unleashed much of its in-house F1 tech on this road-going hypercar”

McLAREN P1

Master of aerodynamics

P1 in brief

The P1 takes advantage of a range of in-house tech and aerodynamic traits used on McLaren’s F1 cars to surpass 322km/h (200mph).

Fresh from its international debut at the Geneva Motor Show, the McLaren P1 is considered the latest pioneer to the enhancement of motoring physics. Form is unquestionably sacrificed for function here: the P1 is certainly not a looker in comparison to other exotic cars, but its aerodynamic finesse helps to make it one of the quickest in the industry. Body panels appear tightly moulded around its powerful internals in homage to a modern Formula One car. The P1’s parallels with the premier motorsporting discipline don’t stop there either as McLaren has unleashed much of its in-house F1 tech on this road-going hypercar – particularly in terms of aerodynamics. One such trait is the recycling of energy thanks to the Instant Power Assist System (IPAS), which catches kinetic energy when braking and converts it into electrical energy that can be used to add a burst of power. The car also features highly adjustable active damping: indeed, in Race mode, the spring rates stiffen by 300 per cent, so the P1 can corner at more than two g. Inside is as primitive as possible to shed weight, and extensive aerodynamic tweaks ensure almost unprecedented levels of downforce for a road car, so the P1 can both cut cleanly through the air and yet stay firmly on the ground.

The statistics…

McLaren P1

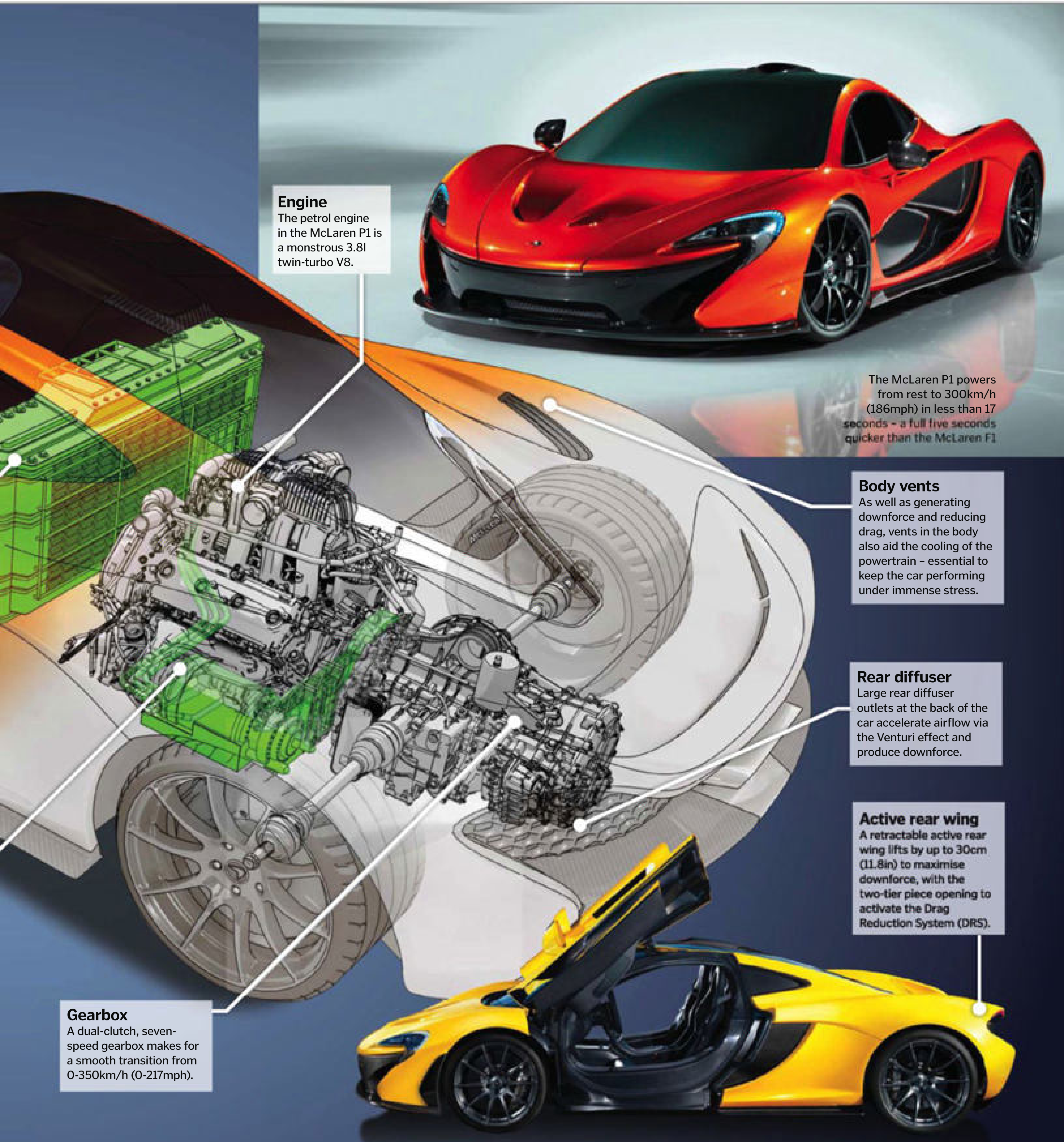
Length: 4,588mm (180.6in)
Weight: 1,400kg (3,086lb)
Engine: V8, 3,800cc, twin-turbo
Transmission: 7-speed twin clutch
Max speed: 350km/h (217mph)
0-100km/h: 2.9sec
Power: 673kW (903bhp)

When can an F1 car create its own weight in downforce?

A At 129km/h **B** At 322km/h **C** Never

Answer:
Such is the astute aerodynamic design of a Formula One car, it can actually generate its own weight in downforce at only 129 kilometres (80 miles) per hour, theoretically allowing you to drive it upside down in a tunnel at this speed.

DID YOU KNOW? *The windscreen wiper on the Koenigsegg Agera R is in an upright resting position to reduce drag*



The McLaren P1 powers from rest to 300km/h (186mph) in less than 17 seconds – a full five seconds quicker than the McLaren F1

Engine
The petrol engine in the McLaren P1 is a monstrous 3.8l twin-turbo V8.

Body vents
As well as generating downforce and reducing drag, vents in the body also aid the cooling of the powertrain – essential to keep the car performing under immense stress.

Rear diffuser
Large rear diffuser outlets at the back of the car accelerate airflow via the Venturi effect and produce downforce.

Active rear wing
A retractable active rear wing lifts by up to 30cm (11.8in) to maximise downforce, with the two-tier piece opening to activate the Drag Reduction System (DRS).

Gearbox
A dual-clutch, seven-speed gearbox makes for a smooth transition from 0-350km/h (0-217mph).

"The Porsche 918 Spyder utilises lightweight efficiency with brute power and aerodynamic refinement"

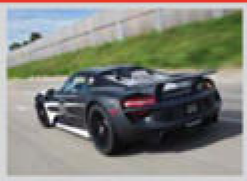
PORSCHE 918 SPYDER
The power of hybrids

918 Spyder in brief
Plug-in hybrid engine technology combines with naturally aspirated V8 combustion engine to produce 593kW (795bhp). It uses just three litres (0.8 gallons) of fuel for every 100km (62mi).

Much in line with the McLaren P1, the Porsche 918 Spyder – due for release this year – utilises lightweight efficiency with brute power and aerodynamic refinement to muster 322 kilometres (200 miles) per hour with ease. The drivetrain and other components weighing over 50 kilograms (110 pounds) in the plug-in hybrid are kept as low and central as possible to improve the centre of gravity and aid handling at speed. In an industry first, the exhaust pipes are also placed high up *above* the engine, though this is for mechanical reasons rather than aerodynamics; the exhaust is occupying the already hot space above the engine, keeping underneath the engine cool enough to mount those all-important electric batteries.

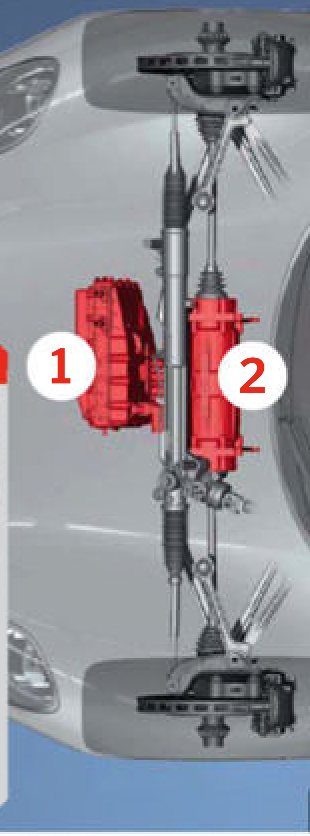
Meanwhile, a carbon monocoque chassis means that the main part of the car is lightweight, while flaps underneath the headlights open to aid cooling of internal components and close at higher speeds to reduce drag. Additionally Porsche Active Suspension Management keeps the car rigid at speed so it cuts sharply through the air.

The statistics...



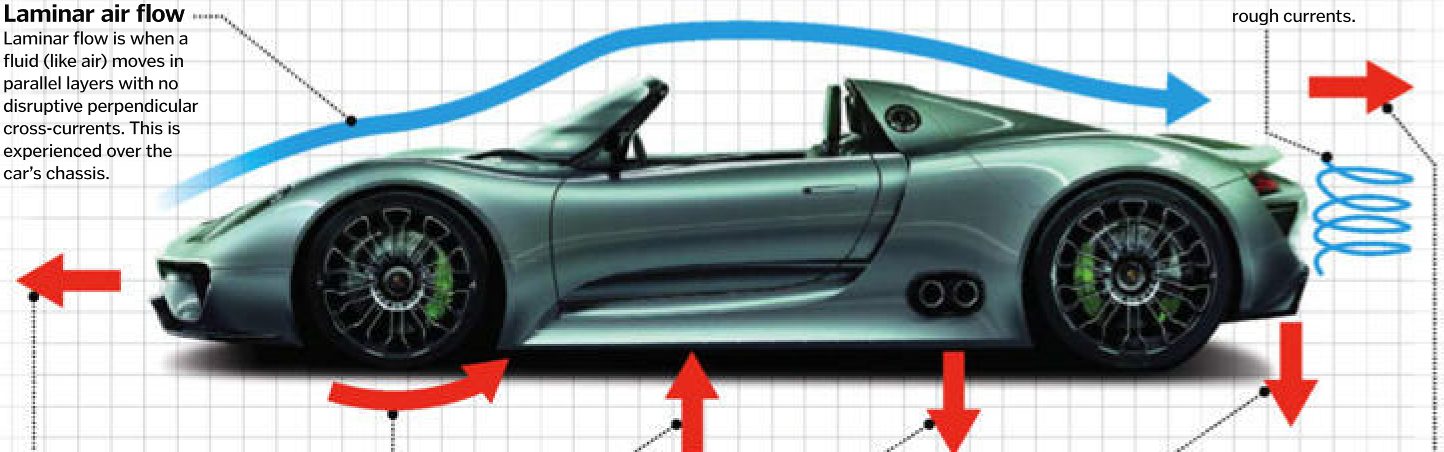
Porsche 918 Spyder

Length: 4,643mm (182.8in)
Weight: 1,700kg (3,747lb)
Engine: V8, 4,600cc engine with hybrid module
Max speed: 325km/h (202mph)
0-100km/h: 3.0sec
Power: 593kW (795bhp)



Driving forces explained

Many forces are acting for and against a hypercar when in motion, as we see here...



Laminar air flow
Laminar flow is when a fluid (like air) moves in parallel layers with no disruptive perpendicular cross-currents. This is experienced over the car's chassis.

Turbulent air flow
Air at the back of the car experiences distortion laterally, with its layers interacting through a series of eddies and rough currents.

Thrust
The forward thrust from the engine counteracts the forces of drag. The more drag that acts on the car, the harder the engine has to work to speed the vehicle up.

Rolling resistance
Rolling resistance is the force acting against the tyres as they turn. The higher the rolling resistance, the more energy (ie fuel) is needed to push the car along.

Lift
Lift counters downforce and is created as air flows around and below the car, pushing it up. Lift in a car is bad: it means loss of traction, which goes against acceleration.

Gravity
Like everything else on our planet, gravity constantly acts on a car to pull the object towards the ground. This is a form of friction, slowing the car down.

Downforce
A downwards thrust created chiefly by the aerodynamic physics of a car such as a spoiler or wing. Downforce is essential to keeping the car planted to the ground.

Drag
Drag is a form of wind resistance defined as still air pushing against a moving object. Drag counteracts thrust, so the more a car speeds up, the more drag increases.

5 TOP FACTS
HYPERCAR TRIVIA

Going it alone
1 The LaFerrari is the first car designed by the famous Italian automotive manufacturer completely in-house, with long-time collaborator Pininfarina having no input.

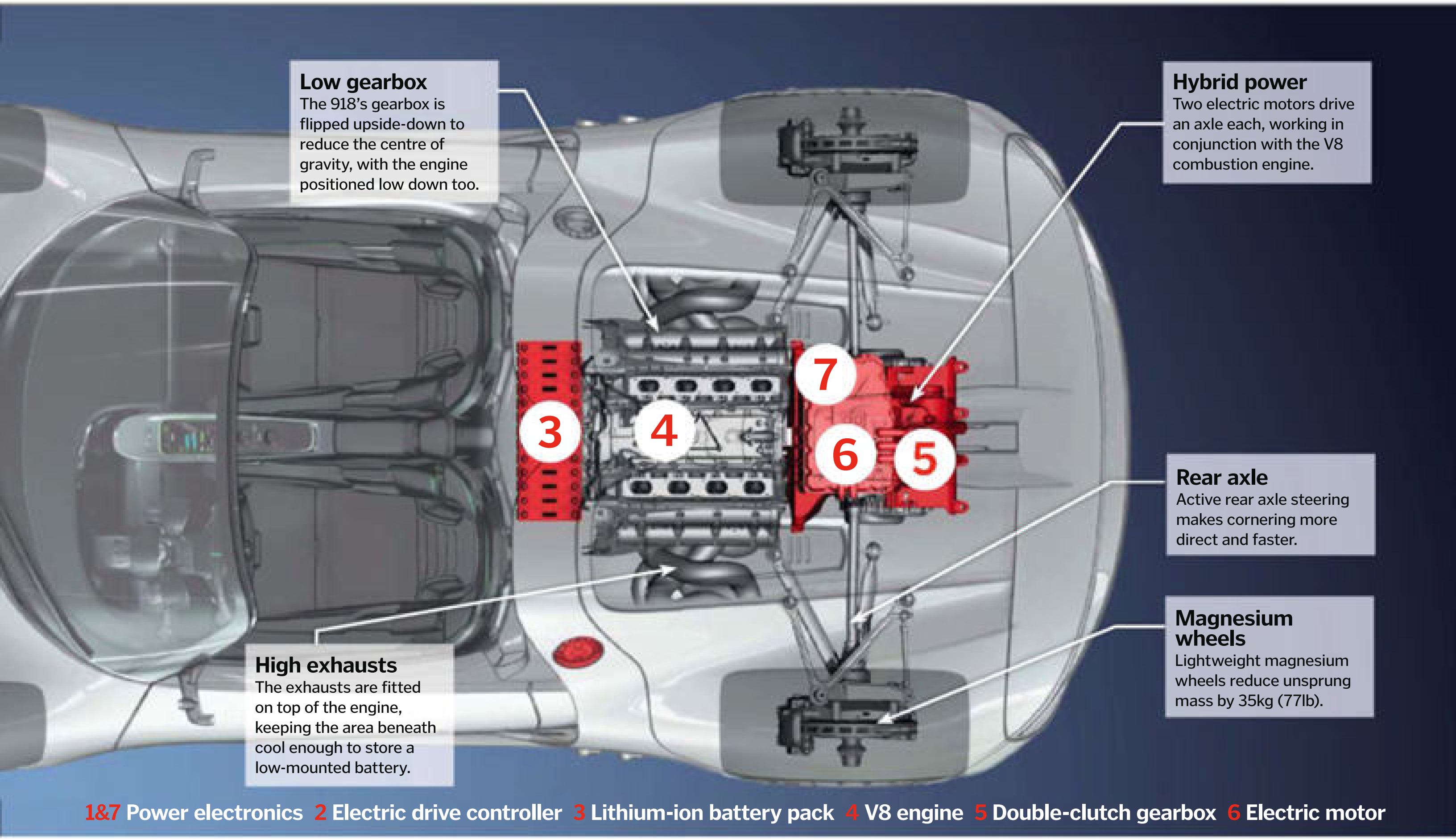
Tyre-shredding speed
2 The Bugatti Veyron is actually limited to 407 kilometres (253 miles) per hour to stop the road tyres from falling apart. Any speed over that will call for costly adapted race rubber.

Going the distance
3 As well as achieving 300 kilometres (186 miles) per hour in the fastest time, the Venom GT also reached the figure in the shortest distance, taking just over a mile to do so.

Limited edition
4 Not only will the Porsche 918 Spyder come with a price tag of over £650,000 ($982,000), but it will also be a limited-edition run, with a fitting 918 vehicles made.

An expensive thrill
5 World-leading performance comes at a cost. The Bugatti Veyron is about £1 million ($1.5 million), while the Lykan Hypersport will retail for a cool £2.2 million ($3.4 million)!

DID YOU KNOW? McLaren has removed the top layer of resin on all carbon fibre on the P1, saving an incredible 1.5kg (3.3lb)!

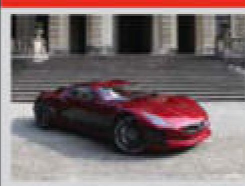


RIMAC CONCEPT ONE
The first full-electric hypercar

Concept One in brief
This soon-for-mass-production hypercar is powered by electric motors delivering 811kW (1,088bhp) to each wheel independently. With no need for an engine or gearbox, this could be the future of motoring.

Although many hypercars of the modern era are embracing hybrid technology in a bid to cut down emissions, the Rimac Concept One is the first to claim fully electric status, eliminating physical boundaries set by combustion engines including rev limits and turbo lag. Instead of a traditional combustion engine, this car's powertrain is divided into four electrical subsystems consisting of a motor, inverter and reduction gearbox, with each subsystem powering one wheel independently. This self-styled All Wheel Torque Vectoring (R-AWTV) generates a staggering 811 kilowatts (1,088 brake horsepower), and in the absence of an engine limited by revs, provides the driver with the added benefit of extremely fast accelerator response across an extremely wide power band. Even better, the 92-kilowatt battery has a decent range too, powering the hypercar for up to 600 kilometres (373 miles) of driving with precisely zero emissions. The low mounting position of the battery and powertrains ensures a good, low centre of gravity for the Concept One (a must-have for any hypercar), and an engineless car does move the goalposts somewhat when it comes to the limitations of a traditional engine. However, the weight of the Concept One's electrical gizmos mean performance is not limitless: of our magnificent lineup in this feature, Rimac's is the heaviest candidate.

The statistics…



Rimac Concept One

Length: 4,548mm (179in)
Weight: 1,950kg (4,299lb)
Engine: Lithium-iron-phosphate battery, 1,400 cells; 650V
Transmission: No gearbox; all wheel drive
Max speed: 304km/h (189mph)
0-100km/h: 2.8sec

"The Hennessey Venom GT uses the lightweight shell of a Lotus Exige to house a gargantuan 7.0-litre engine"

HENNESSEY VENOM GT

Off-the-scale power

Venom GT in brief

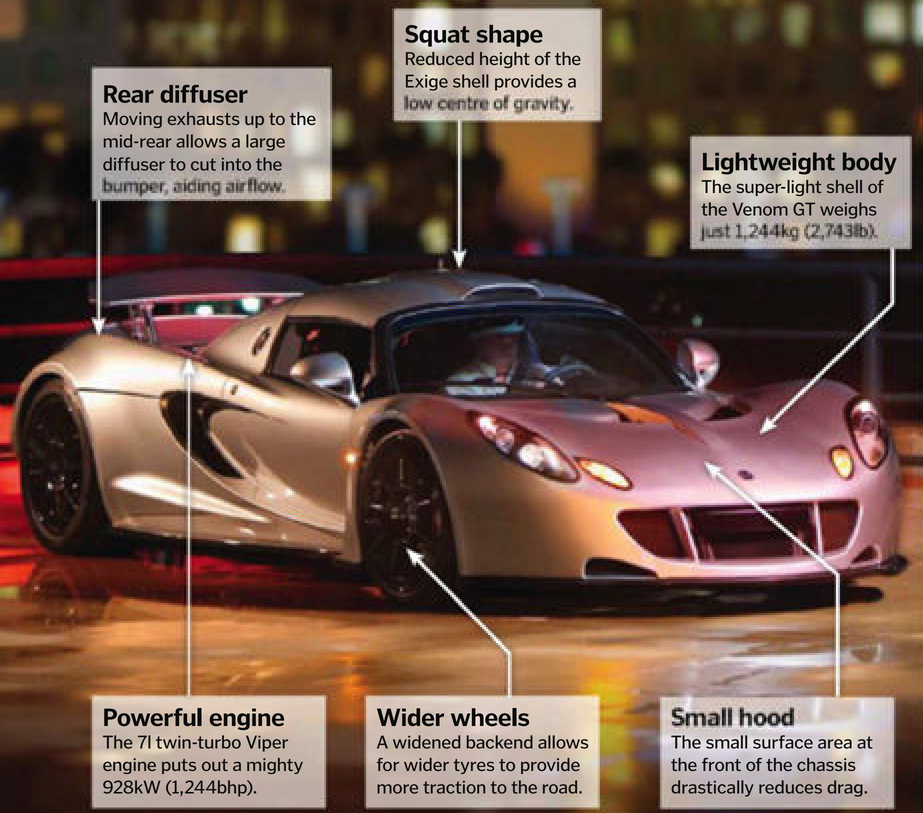
Essentially a lot of power fitted into an extremely small and lightweight body. Hennessey took the 1,000-plus horsepower twin-turbo Viper engine and placed it inside a modified Lotus Exige shell.

The current Guinness World Record holder for the fastest 0-300-kilometre (0-186-mile)-per-hour dash – which was achieved in under 14 seconds – the Hennessey Venom GT uses the lightweight shell of a more modest Lotus Exige to house the gargantuan 7.0-litre twin-turbo Viper engine. The power-to-weight ratio here is crazy: 928 kilowatts (1,244 brake horsepower) powers 1,244 kilograms (2,743 pounds), providing 746 kilowatts (1,000 horsepower) per ton. Such little weight resistance helps the Venom GT fly, while the small nature of the body means there's simply less surface area for resistant forces to act on, so the car can cut through the air at an eye-watering pace.

The statistics...

Hennessey Venom GT

Length: 4,655mm (183.3in)
Width: 1,960mm (77.2in)
Weight: 1,244kg (2,743lb)
Engine: V8, 7,000cc, twin-turbo
Transmission: 6-speed manual, rear wheel drive
Max speed: 443km/h (275mph)
0-100km/h: 2.7sec
Power: 928kW (1,244bhp)



KOENIGSEGG AGERA R

Wind-driven downforce

Agera R in brief

More power and less weight over the original Agera means the maths is simple: the Agera R reaches 200km/h (124mph) half a second faster. It also runs on biofuel.

As if the original 2011 Koenigsegg Agera wasn't quick enough, the new 2013 Agera R has upped the ante, producing 850 kilowatts (1,140 horsepower) from the same 5.0-litre, twin-turbocharged V8 powertrain. Key differences come in that hallowed power-to-weight ratio: while the power in the Agera R has gone up, the bulk over the original has come down, thanks to some clever weight-saving measures. Take in the new 48.3-centimetre (19-inch) wheels; not only are they made from carbon fibre (what else!), but they're hollow-spoked too, providing a net save of 40 per cent over similar alloy wheels. While other hypercars manage downforce via an active rear wing that changes height according to speed, the Agera R changes its angle of wing to literally target downforce upon the rear.

Further, the angle is not determined by heavy hydraulics, but by the pressure of the wind itself. With the angle of the wing dictated by wind resistance, this compensates for headwind or tailwind at the same given speed. Likewise, the new Aero Exhaust is shaped to improve underbody air release, ensuring this latest Koenigsegg of continued aerodynamic evolution and greater speed.

The statistics...

Koenigsegg Agera R

Length: 4,293mm (169in)
Width: 1,996mm (78.6in)
Weight: 1,330kg (2,932lb)
Engine: V8, 5,000cc, twin-turbo
Transmission: N7-speed dual clutch, rear wheel drive
Max speed: 439km/h (273mph)
0-100km/h: 2.9sec
Power: 850kW (1,140bhp)

DID YOU KNOW? The Agera R is evolving to work with eco-friendly fuel including E85 which only contains 15 per cent gasoline

NISSAN DELTAWING

Ultra-light chassis

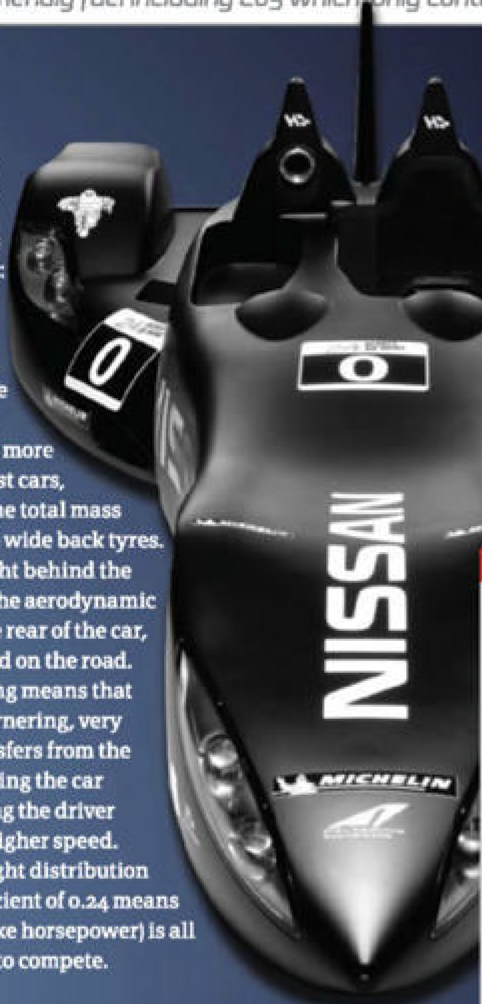
DeltaWing in brief

A sleek aerodynamic profile and impeccable weight distribution ensures impressive balance and demands less power.

Although not a commercial production car, Nissan's DeltaWing is a motoring phenomenon. The rip-roaring race car reaches 100 kilometres (62 miles) per hour in just 3.3 seconds and powers on to a top speed of 315 kilometres (196 miles) per hour – all from a modest four-cylinder, 1.9-litre turbocharged engine. Such ferocious performance is delivered by well-thought-out physics split into two factors.

The first factor is the car's mass: the majority of the chassis and body panels on the DeltaWing are made from carbon fibre (a composite famed for being much lighter than steel), aluminium and other materials more commonly used as vehicle body panels. Being lighter – the DeltaWing weighs a mere 490 kilograms (1,080 pounds) – means less grunt from the engine is needed to get the vehicle moving swiftly, and reduces the car's overall unsprung mass, improving handling.

The second factor is the position of weight: the rear engine, rear wheel drive layout, coupled with the narrow front and wide backend, is such that weight distribution is more rearward than on most cars, with 72.5 per cent of the total mass sitting between those wide back tyres. With most of the weight behind the driver, 76 per cent of the aerodynamic downforce acts on the rear of the car, keeping it well planted on the road. Similarly, streamlining means that when braking and cornering, very little lateral load transfers from the rear to the front, keeping the car balanced and enabling the driver to enter corners at a higher speed. Near-impeccable weight distribution and a tiny drag coefficient of 0.24 means 261 kilowatts (350 brake horsepower) is all the DeltaWing needs to compete.



The statistics...

Nissan DeltaWing

Length: 4,650mm (183in)

Width: Front 760mm (29.9in); rear 2,080mm (81.9in)

Weight: 490kg (1,080lb)

Engine: Four cylinder, 1,900cc, turbo

Transmission: 5-speed sequential

Max speed: 315km/h (196mph)

0-100km/h: 3.3sec

Power: 261kW (350bhp)

LAFERRARI

The Ferrari Enzo reimagined

Ferrari's new hypercar is effectively the 2013 equivalent of its last true hypercar, the 2003 Ferrari Enzo. Although LaFerrari retains the same overall length and wheelbase as the Enzo, key specification adjustments allow for this new model to go even faster.

LaFerrari is 43 millimetres (1.7 inches) narrower and 31 millimetres (1.2 inches) shorter than the Enzo to the floor, with a 35-millimetre (1.4-inch) lower centre of gravity and greater weight distribution to the rear (by a whole two per cent). This means the car can slip through the air quicker and better hug the ground around bends – both crucial ingredients for going fast. Ferrari is another high-performance brand keen to clean up its act, so LaFerrari has also employed hybrid technology in order to bring overall exhaust emissions down.

Tapered front
LaFerrari has a smaller point of contact with air at the front of the vehicle, reducing wind resistance.

Bumper vent
Large vents in the front bumper push air quickly underneath the car, enabling LaFerrari to stick to the road, even at speed.

Side vent
These assist with cooling of the engine to allow for optimum performance.

"It's capable of tracking multiple projectiles as they move across the sky using a nearby radar station"

Mine-shaft elevators

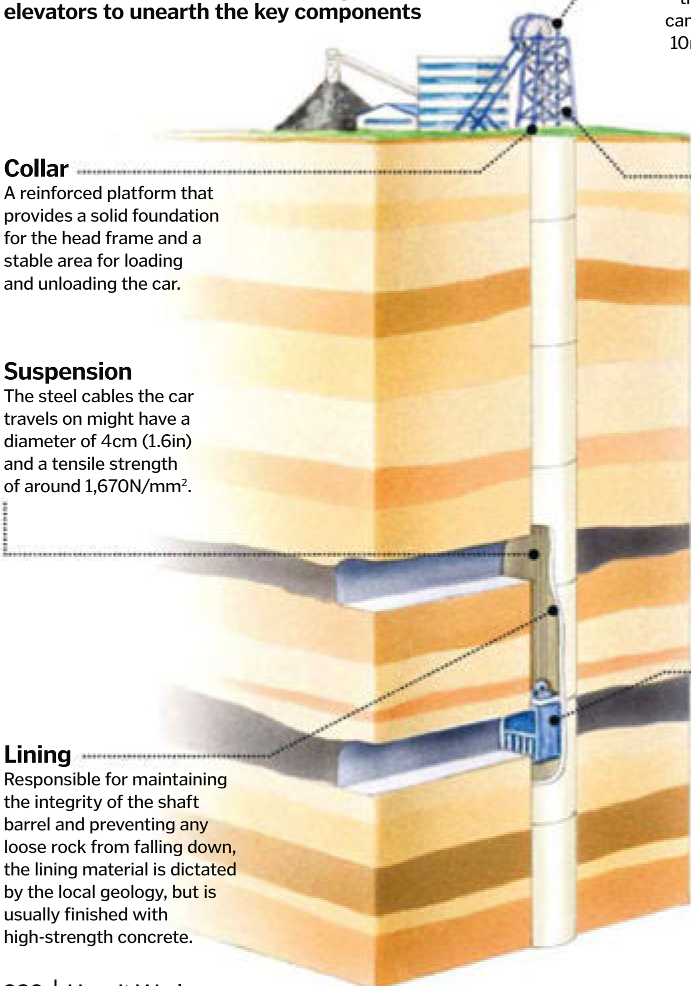
Getting to the depths of the planet would be a whole lot harder without these super-strong platforms

Where underground seams of coal and other minerals are made accessible via a vertical shaft, an elevator is required to lower mine workers down to the appropriate depth. The shafts themselves are circular or rectangular and can employ timber and brick to shore up the walls, although steel and concrete are much stronger support materials used in deeper mines where the lateral pressure is greater.

The basic mine-shaft elevator consists of a drum with a length of suspension cable coiled around it, which is attached at one end to the passenger-carrying car. Both the thickness of the cable and the material it's made of will depend on the type and depth of the mine shaft. A counterweight that makes up around 40 per cent of the car's maximum weight hangs on the other end of the cable, helping to control its movement.

Subterranean lift mechanics

Take a tour of one of these underground elevators to unearth the key components



Drum
The hydraulic engine that turns the drum can hoist in excess of 10m (33ft) a second.

Collar
A reinforced platform that provides a solid foundation for the head frame and a stable area for loading and unloading the car.

Head frame
It goes by many names, such as pit frame and winding tower, but essentially this structure's job is to support the hoist/drum.

Suspension
The steel cables the car travels on might have a diameter of 4cm (1.6in) and a tensile strength of around 1,670N/mm².

Car
Depending on the type of mine, the cars can easily carry dozens of miners and/or heavy equipment.

Lining
Responsible for maintaining the integrity of the shaft barrel and preventing any loose rock from falling down, the lining material is dictated by the local geology, but is usually finished with high-strength concrete.

Defending against projectiles like rockets is a cinch with a laser that can work at the speed of light

Meet the laser truck

Why has Boeing created a military vehicle with a giant laser cannon mounted on top?

The technology to create high-power lasers has been around for decades. It's only in the last 20 years, however, with the increasingly sophisticated use of computers on the battlefield and power-output efficiencies of lasers, that tactical use of lasers for defence has become practical.

Boeing has taken this a step further by strapping a ten-kilowatt solid-state laser to the roof of an eight-wheeled, 370-kilowatt (500-horsepower), Oshkosh Heavy Expanded Mobility Tactical Truck that also houses the laser's power source. It's been called the High Energy Laser Technology Demonstrator (HEL TD), and it's capable of acquiring and tracking multiple projectiles as they move across the sky using a nearby radar station, then target them by focusing a beam of intense laser energy onto the projectile until it explodes. It's more cost effective than the previous deuterium fluoride laser versions (which cost several thousand dollars in fuel every time they were fired) and there's also plenty of scope to move up to even more powerful, 100-kilowatt lasers.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"As the rotor assembly rotates the staggered magnetic claw poles create a magnetic field"

Automotive alternators

How do these devices generate the energy to power a car's electrical systems?

Alternators are electromechanical devices that convert mechanical energy into alternating-current (AC) electrical energy. This process is useful in an automotive context as it allows the vehicle to self-charge its battery while being driven.

In an automotive alternator, the mechanical energy is delivered by the vehicle's crankshaft, which rotates. This rotational energy is passed via a drive belt and pulley to the alternator, and replicates it in an internal rotor shaft.

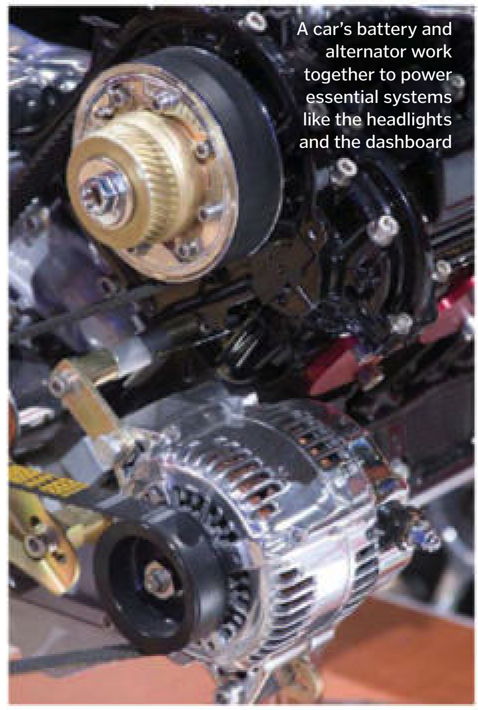
The turning of the alternator's rotor shaft causes an attached iron core, surrounding field winding and set of staggered magnetic claw poles to rotate at high speed (up to thousands of times per minute). This entire assembly is referred to as the alternator's rotor, with it slotting into another element called the stator.

The alternator's stator is a laminated soft iron, roughly spherical component wrapped with, typically, three sets of copper phase windings. The stator, unlike the rotor, is fixed in place, attached to the inside of the alternator's housing. As mentioned, the rotor sits within the stator while it spins, with the two offset slightly to avoid any direct contact.

As the rotor assembly rotates the staggered magnetic claw poles (with north and south poles alternating) generate a magnetic field. Because the field lines continuously change, however – due to the north-south polarity of the claw poles – the flux within the stator changes too, inducing an alternating current to flow through its phase windings.

As the current in the stator's phase windings is alternating, it needs to be converted into direct current (DC) for use in battery charging. This is achieved by feeding the alternating current in each phase winding through stator leads and into a set of diodes (two for each lead). Known as rectifiers, these diodes ensure that current flows in a single direction.

The total flow of direct current from each of the phase windings combined is controlled by a regulator unit. This prevents an excess of direct current from being fed into the vehicle's battery – something that if left unchecked would cause it to overcharge and potentially explode.



A car's battery and alternator work together to power essential systems like the headlights and the dashboard

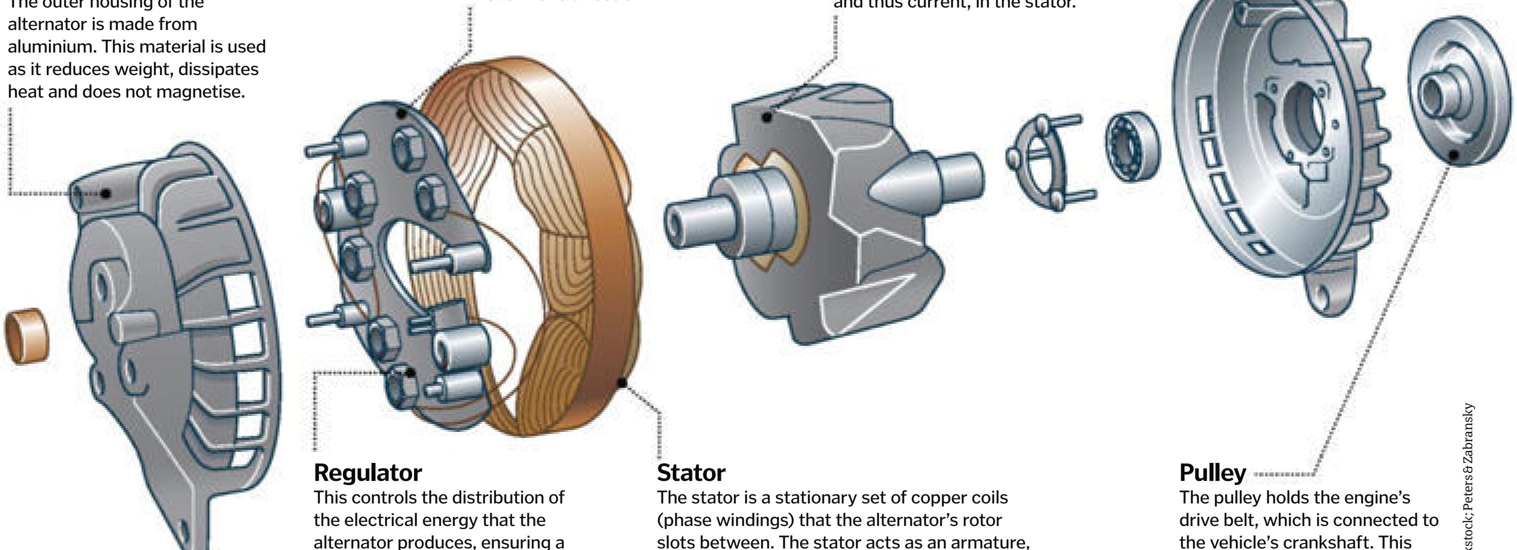
Alternator anatomy

We pull apart an alternator to see how a number of components work in harmony

Casing
The outer housing of the alternator is made from aluminium. This material is used as it reduces weight, dissipates heat and does not magnetise.

Diode assembly
The diodes convert the AC energy produced by the alternator into usable DC by only letting current move in one direction.

Rotor assembly
The rotor is made up of claw poles placed around a series of field windings and an iron core. The poles alternate in a staggered pattern to induce flux, and thus current, in the stator.



Regulator
This controls the distribution of the electrical energy that the alternator produces, ensuring a safe power supply to the vehicle's battery and electrical systems.

Stator
The stator is a stationary set of copper coils (phase windings) that the alternator's rotor slots between. The stator acts as an armature, inducing voltage due to the influence of the rotor-generated magnetic field.

Pulley
The pulley holds the engine's drive belt, which is connected to the vehicle's crankshaft. This supplies the alternator's rotor shaft with rotational energy.


✓Yes
✓Yes
×No
✓Yes
✓Yes
✓Yes
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"If all the Triple-E's containers were stacked, the tower would almost reach Earth's stratosphere!"

The largest cargo ship in the world

The Triple-E container vessel rewrites the concept of what is deemed big, carrying mighty loads across the ocean

What is big? A hippopotamus? A giant redwood? An aircraft carrier? No, they *were* thought of as big – once. Today they are rendered mere dwarfs compared to the Triple-E container vessel, a 165,000-ton, 400-metre (1,312-foot)-long behemoth capable of carrying 18,000 containers over thousands of miles. It is quite simply massive and, when viewed close up, looms over human, machine and building alike. For a bit of perspective, the Triple-E can carry so many containers that if they were all stacked on top of each other, the tower would almost reach Earth's stratosphere.

Indeed, the Triple-E is no ordinary container vessel and its construction has required its manufacturer – Danish firm Maersk – to completely redesign almost every component of the freighter. Everything from the hull and the powerplant, through to the propulsion and the deck layout has had to be adjusted to allow for the creation of a vessel that can safely and efficiently carry such tremendous weight (for a breakdown of these, see the 'Triple-E anatomy' diagram). Without many technological advancements the Triple-E would, quite simply, be impractical.

Starting from June 2013 the Triple-E – which gets its name from its focus on economy of scale, energy efficiency and environmental protection – is to begin its primary role, braving the long-haul trade passages between Asia and Europe, which are getting ever busier. Here the Triple-E will make use of its new 'slow-steaming' method of transport – a process where the vessel travels at a reduced speed in order to deliver significantly reduced fuel consumption and CO_2 emissions. This will enable the Triple-E to carry far more goods than any other container ship before it for any given journey and, on top of that, with less impact on the environment.

The statistics...

Triple-E

Beam: 59m (194ft)
Draught: 14.5m (47ft)
Height: 73m (239ft)
Length: 400m (1,312ft)
Deadweight: 165,000 tons
Container capacity: 18,000 TEU
Top speed: 23 knots (42km/h; 26mph)
Engine power: ~60,000kW (~81,577hp)

Triple-E anatomy

Take a close-up look at this container-carrying colossus

Propeller
Unlike other container vessels, the Triple-E has a twin propeller system. The propellers, which measure 9.8m (32.2ft) in diameter, are quad bladed and allow the ship to cruise smoothly, even in the choppiest waters.

Engines
The Triple-E is equipped with two MAN ultra-long-stroke diesel engines, each rated at 32MW (42,913hp). These have a low fuel consumption of 168g/kWh and are designed specifically for slow-steaming (travelling more efficiently at lower speeds) operations.

Recovery systems
The ship is equipped with a brace of waste heat recovery (WHR) systems. These convert excess heat from the engines into high-pressure steam to drive an electric turbine. This improves the overall energy efficiency.

Containers
A total of 18,000 TEU containers can be carried by the Triple-E. They can house a wide variety of freight ranging from food and drink through to clothing, electronics and more.

Deckhouse
The Triple-E's deckhouse can accommodate 34 people and is located farther forward on the deck than usual; this means containers can be stacked higher in front of the bridge, improving capacity.

458m

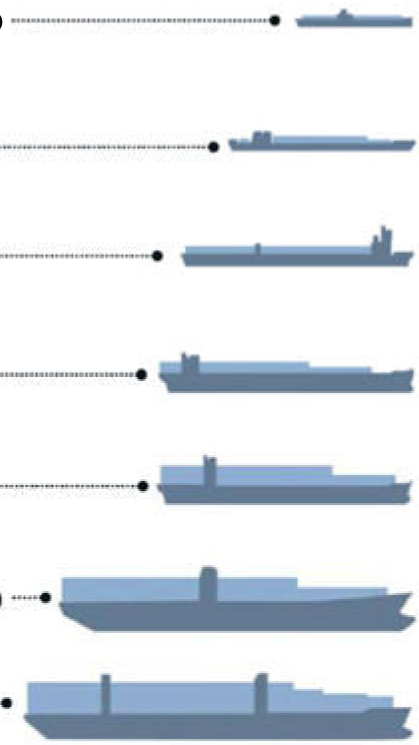
BIGGEST SHIP IN HISTORY

Despite being the largest container vessel, the Triple-E will not be the biggest ship ever. That accolade goes to the now scrapped 458-metre (1,503-foot)-long Knock Nevis supertanker, which outsized the Triple-E by 58 metres (191 feet).

DID YOU KNOW? The Triple-E is 59m (194ft) longer than the formidable USS Enterprise aircraft carrier

The Triple-E compared

How does the latest member of the Maersk fleet measure up to former container ships?



Early container ship (1956)
Length: 137m (449ft)
Beam: 17m (56ft)
Capacity: 500-800 TEU
(20-foot equivalent units)

Fully cellular (1970)
Length: 215m (705ft)
Beam: 20m (66ft)
Capacity: 1,000-1,500 TEU

Panamax (1980)
Length: 250m (820ft)
Beam: 32m (105ft)
Capacity: 3,000-3,400 TEU

Panamax Max (1985)
Length: 290m (951ft)
Beam: 32m (105ft)
Capacity: 3,400-4,500 TEU

Post-Panamax (1988)
Length: 285m (935ft)
Beam: 40m (131ft)
Capacity: 4,000-5,000 TEU

Post-Panamax Plus (2000)
Length: 300m (984ft)
Beam: 43m (141ft)
Capacity: 6,000-8,000 TEU

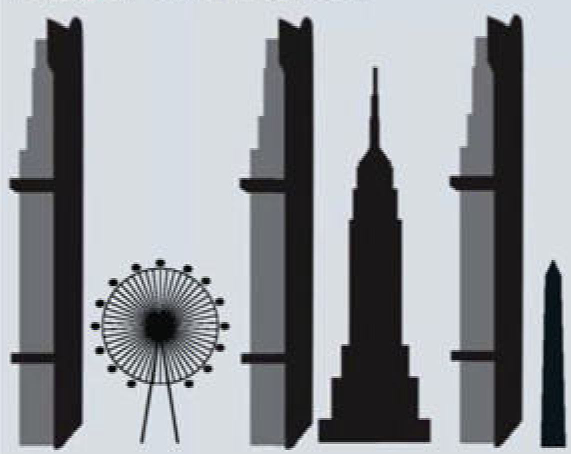
Triple-E (2013)
Length: 400m (1,312ft)
Beam: 59m (194ft)
Capacity: 18,000 TEU

Tower
The Triple-E is controlled from a tower mounted to the top of the deckhouse. The forward positioning of the tower allows a clearer and wider viewing angle when the vessel is loaded with containers.

Rows
The deck of the Triple-E is broken down into 23 rows, with each capable of carrying stacked lines of containers. This arrangement grants terminal cranes easier access for loading and unloading.

Hull
The hull of the Triple-E is a flat 'U' shape rather than its predecessor's sharper 'V'-shaped one. This enables significantly more containers to be stored at lower levels, improving overall capacity by 16 per cent, as well as stability.

Bigger than what?



London Eye
If the Triple-E were tipped on its end, it would be three times the height of the 135-metre (443-foot)-tall observation wheel on the Thames.

Empire State Building
With the roof of the Empire State at 381 metres (1,250 feet) high, the Triple-E would be 20 metres (65 feet) taller if placed on its end.

Washington Monument
It's not all about height. Weighing in unloaded at 165,000 tons, the Triple-E is more than double the weight of this iconic Washington landmark.

Firestorms

From tornado-force winds to superhot flames, dare you discover nature's most violent infernos?

50,000km²

BIGGEST-EVER BUSHFIRE

The Black Thursday bushfires on 6 February 1851 burnt the largest area of any Australian bushfire in European-recorded history: a quarter of Victoria!

DID YOU KNOW? *Large wildfires have increased by 300 per cent in western USA since the mid-Eighties*

Firestorms are among nature's most violent and unpredictable phenomena. Tornado-force winds sweep superhot flames of up to 1,000 degrees Celsius (1,800 degrees Fahrenheit) through buildings and forests alike. Victims often suffocate before they can flee and entire towns can be obliterated. Survivors of firestorms describe darkness, 100-metre (330-foot)-high fireballs and a roaring like a jumbo jet. To give you an idea of the sheer heat, firestorms can be hot enough to melt aluminium and tarmac, warp copper and even turn sand into glass.

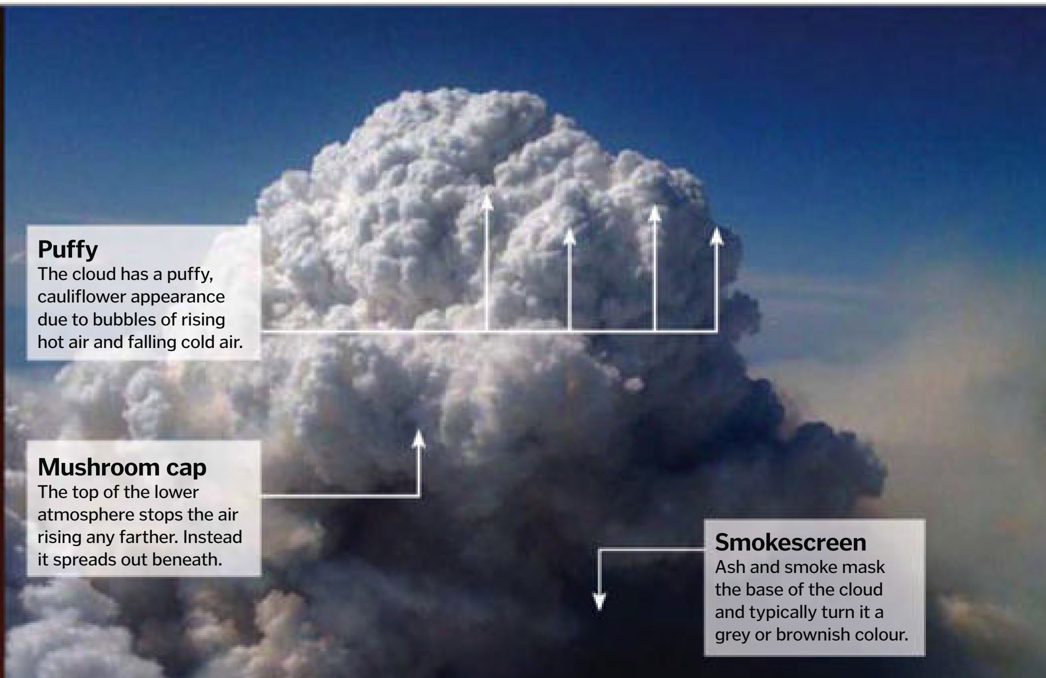
Firestorms happen worldwide, especially in the forests of the United States and Indonesia, and in the Australian bush. They occur mostly in summer and autumn when vegetation is tinder dry. Although they are a natural phenomenon, among the most devastating were triggered deliberately. During World War II, for instance, Allied forces used incendiaries and explosives to create devastating firestorms in Japanese and German cities. Firestorms also erupted after the cataclysmic impact 65.5 million years ago that many believe to have triggered the extinction of the dinosaurs.

Climate change may be already increasing the risk of mega-fires by making summers ever hotter and drier. The Rocky Mountain Climate Organization, for example, has reported that from 2003 to 2007, the 11 western US states warmed by an average of one degree Celsius (1.7 degrees Fahrenheit). The fire danger season has gone up by 78 days since 1986.

The risk of an Australian firestorm striking a major city has also heightened in the last 40 years. Climate change may have exacerbated this by increasing the risk of long heat waves and extremely hot days. In January 2013 alone, a hundred bushfires raged through the states of New South Wales, Victoria and Tasmania following a record-breaking heat wave. Maximum daily temperatures rose to 40.3 degrees Celsius (104.5 degrees Fahrenheit), beating the previous record set in 1972.

Firestorms can happen during bush or forest fires, but are not simply wildfires. Indeed, a firestorm is massive enough to create its own weather (see boxout). The thunderstorms, powerful winds and fire whirls – mini tornadoes of spinning flames – it can spawn are all part of its terrifying power.

The intense fire can have as much energy as a thunderstorm. Hot air rises above it, sucking in additional oxygen and dry debris, which fuel and spread the fire. Winds can reach ▶



How do mushroom clouds form?

The terrifying mushroom clouds produced after nuclear bombs are examples of pyrocumulus, or fire, clouds. This towering phenomenon is caused by intense ground heating during a firestorm. Their tops can reach an incredible nine kilometres (six miles) above the ground. When the fire heats the air, it rises in a powerful updraft that lifts water vapour, ash and dust. The vapour starts to cool high in the atmosphere and condenses as water droplets on the ash. As a result, a cloud forms that can quickly become a thunderstorm with lightning and rain, if enough water is available. The lightning can start new fires, but on the bright side, rain can extinguish them.

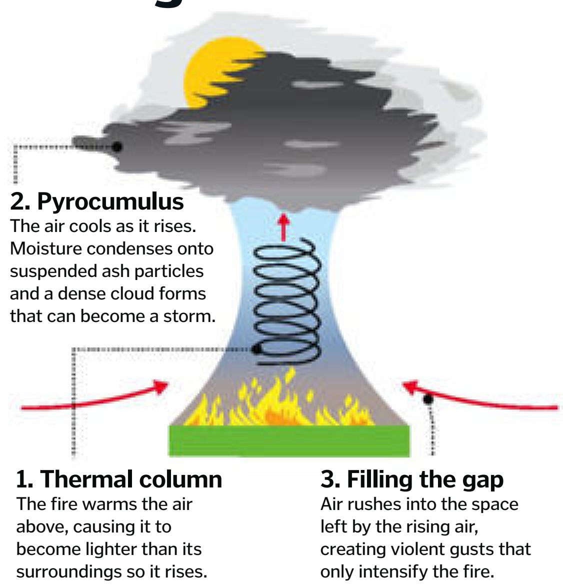
How firestorms change the weather

Firestorms can release as much energy as a lightning storm on a hot summer's afternoon.

Warm air above the fire is lighter than the surrounding air so it rises; the swirling pillar of lifting air above the fire is called a thermal column. This tornado-like structure is responsible for a firestorm's power. Under the right weather conditions, air can rise inside the column at eye-watering speeds of 270 kilometres (170 miles) per hour!

Cooler air gusts into the space left behind by the ascending air, causing violent winds that merge fires together into a single intense entity. They also blow in oxygen, wood and other flammable material that serve to fuel and intensify the blaze.

Turbulent air spiralling around the thermal column can spawn fire tornadoes and throw out sparks. These can set light to trees and houses tens of metres away, increasing the conflagration's range.

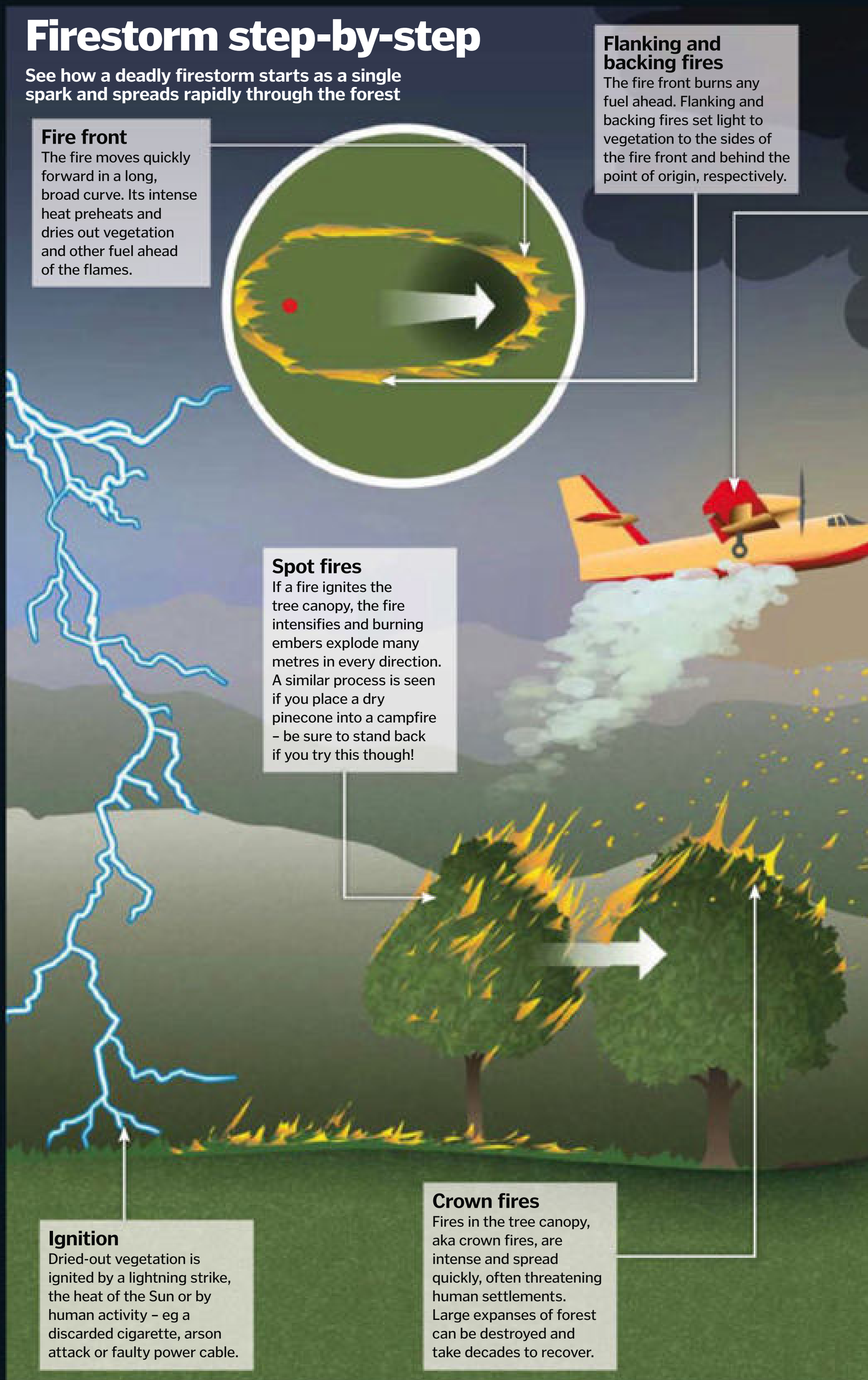


"Fire tornadoes fling flaming logs and other burning debris across the landscape, spreading the blaze"

tornado speed – tens of times the ambient wind speeds. The huge pillar of rising air – called a thermal column – swirling above the firestorm can generate thunderclouds and even lightning strikes that spark new fires.

The thermal column, in turn, can spawn a number of fiery tornadoes, which can tower to 200 metres (650 feet) and stretch 300 metres (980 feet) wide, lasting for at least 20 minutes. These fling flaming logs and other burning debris across the landscape, spreading the blaze. The turbulent air can gust at 160 kilometres (100 miles) per hour, scorching hillsides as far as 100 metres (330 feet) away from the main fire. It's far more powerful than a typical wildfire, which moves at around 23 kilometres (14.3 miles) per hour – just under the average human sprint speed.

Like all fires, firestorms need three things to burn. First is a heat source for ignition and to dry fuel so it burns easier. Fuel, the second must, is anything that combusts, whether that be paper, grass or trees. Thirdly, all fires need at least 16 per cent oxygen to facilitate their chemical processes. When wood or other fuel burns, it reacts with oxygen in the surrounding air to release heat and generate smoke, embers and various gases. Firestorms are so intense that they often consume all available oxygen, suffocating those who try to take refuge in ditches, air-raid shelters or cellars.



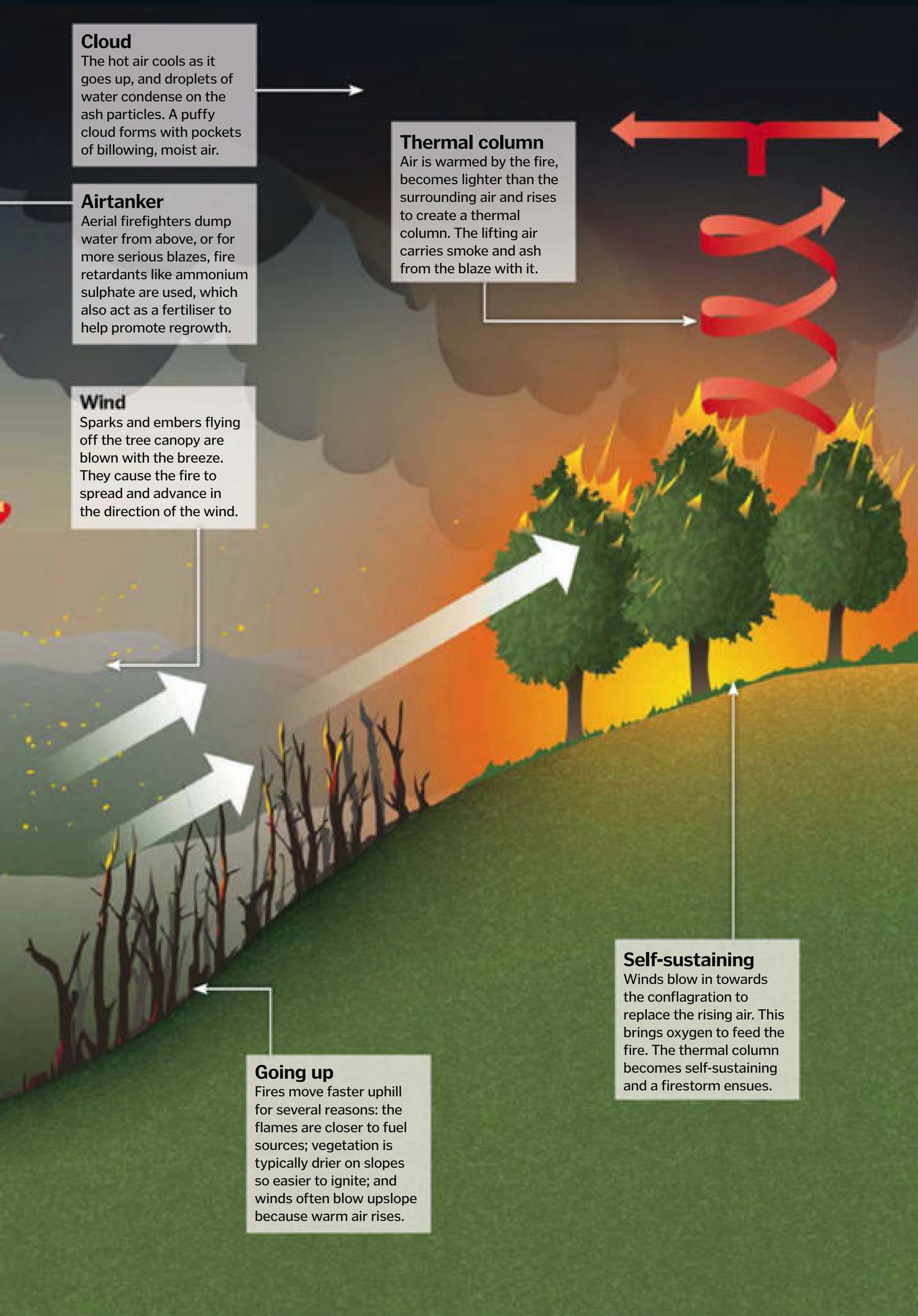
Fighting firestorms

Fire wardens, air patrols and lookout stations all help detect fires early, before they can spread. Once a fire starts, helicopters and air tankers head to the scene. They spray thousands of gallons of water, foam or flame-retardant chemicals around the conflagration. In the meantime, firefighters descend by rope or parachute to clear nearby flammable material.

We can reduce the risk of fire breaking out in the first place by burning excess vegetation under controlled conditions. Surprisingly this can actually benefit certain plants and animals. Canadian lodgepole pines, for example, rely partly on fire to disperse their seeds. Burning also destroys diseased trees and opens up congested woodland to new grasses and shrubs, which provides food for cattle and deer.

Vegetation in fire-prone areas often recovers quickly from a blaze. Plants like Douglas fir, for instance, have fire-resistant bark – although it can only withstand so much heat. Forest owners help flora to return by spreading mulch, planting grass seed and erecting fences.

DID YOU KNOW? The biggest man-made firestorm took place in Dresden, Germany, in 1945; 70 per cent of the city was destroyed



Five mega firestorms

1 Black Saturday

In 2009, one of Australia's worst bushfires killed 173 people, injured 5,000, destroyed 2,029 homes, killed numerous animals and burnt 4,500 square kilometres (1,700 square miles) of land. Temperatures may have reached 1,200 degrees Celsius (2,192 degrees Fahrenheit).

2 Great Peshtigo

The deadliest fire in American history claimed 1,200-2,500 lives, burned 4,860 square kilometres (1,875 square miles) of Wisconsin and upper Michigan and destroyed all but two buildings in Peshtigo in 1871.

3 Ash Wednesday

More than 100 fires swept across Victoria and South Australia on 16 February 1983, killing 75 people, destroying 3,000 homes and killing 50,000 sheep and cows. It was the worst firestorm in South Australia's history.

4 Hamburg

This firestorm brought on by an Allied bomb strike in 1943 killed an estimated 44,600 civilians, left many more homeless and levelled a 22-square-kilometre (8.5-square-mile) area of the German city. Hurricane-force winds of 240 kilometres (150 miles) per hour were raised.

5 Great Kanto

A 7.9-magnitude earthquake on 1 September 1923 triggered a firestorm that burned 45 per cent of Tokyo and killed over 140,000. This included 44,000 who were incinerated by a 100-metre (330-foot) fire tornado.

"The granite foundations of Table Mountain deflected energy down, causing the uplift of rock"

What causes rogue waves?

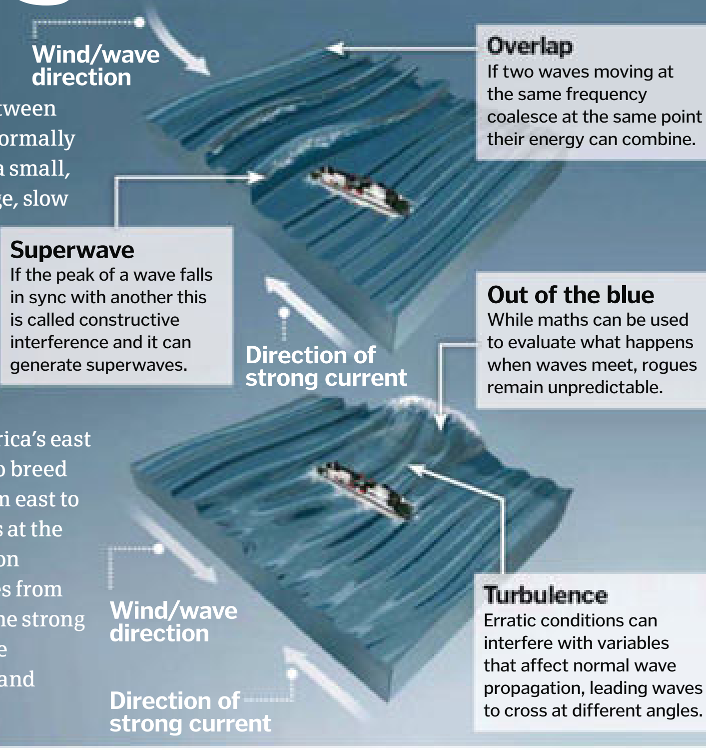
What are these freakishly giant waves that appear as if from nowhere far out at sea?

Maritime history has long told of infeasibly tall waves that strike suddenly during calm seas and topple boats. And yet to date little is understood about what causes these mystery waves. An ESA project confirmed the existence of these mammoth swells when it recorded ten waves all over 25 metres (80 feet) during a three-week period in 2001.

A rogue wave is defined as being around three times the average height of the other waves around it. So they needn't actually be massive – just surprisingly large compared with the general sea state. Their very nature makes it difficult to predict or pinpoint their exact cause as factors such as water depth, currents and many other variables will all affect the propagation and development of a single wave.

Energy can be exchanged between multiple waves to generate abnormally large ones. For example, when a small, fast wave catches up with a large, slow wave, the energy of both can combine to create a single, high-intensity mutant wave.

There are also specific regions of Earth more prone to rogues. The interaction of surface waves and the Agulhas Current near South Africa's east coast, for example, is thought to breed giant waves that propagate from east to west. Environmental engineers at the University of Wisconsin-Madison discovered that when fast waves from one direction interacted with the strong currents moving in the opposite direction, a wave could rise up and 'climb' the current's wall.



Why is Table Mountain so flat?

Discover the unusual geology that has kept this peak so level-headed

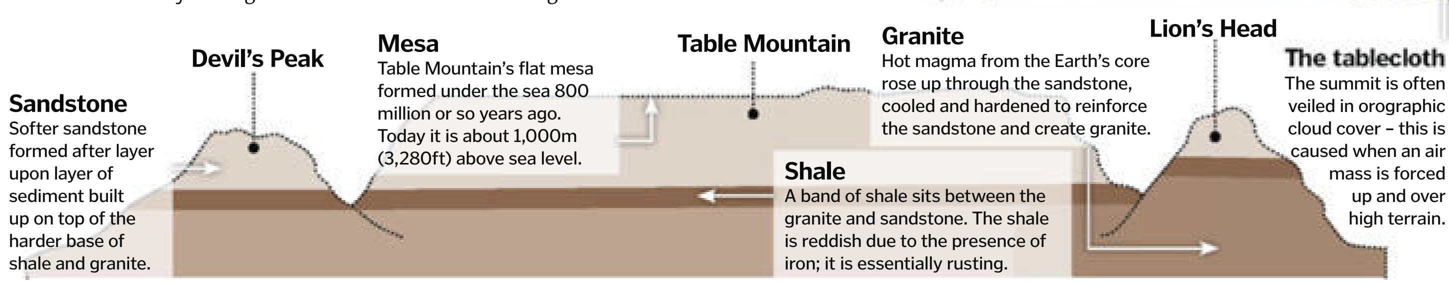
This well-known mountain in western South Africa is actually among the oldest on the planet and it all began with the formation of sandstone in the ocean.

Sandstone is a sedimentary rock that usually forms underwater when grains of sand settle and are then buried under many more tons of sand. The immense weight causes the deepest grains to cement together. In the case of Table Mountain this sandstone began to form a shale-based continental shelf.

Hot magma welling up from the centre of the Earth 600 million years ago infiltrated the shale and then cooled to create a hard foundation of Precambrian granite and slate. Over the following centuries, more and more sediment settled on top of this igneous foundation, creating a new, softer sandstone topper.

165 million years ago Earth's slow-moving plates began to divide the then supercontinent Pangaea in two. This caused the planet's crust to bunch up and form fold mountains. However, the granite foundations of Table Mountain stood firm and instead deflected energy downwards, causing the uplift of rock and the emergence of Table Mountain above the sea.

The Table Mountain plateau overlooks Table Bay and Cape Town



"As much of the jaguar's home has been eliminated, these covert cats have been forced out into the open"

How jaguars survive

When the odds are stacked against you, how do you survive if your habitat is being wiped out?

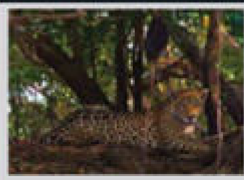
The jaguar (Panthera onca) is the largest cat of the Americas and the third largest in the world after lions and tigers. While they can sometimes be mistaken for leopards due to their characteristic black-ringed markings, jaguars have a distinctive black spot at the centre of the rosette. Interestingly, although the base colour of most jaguar fur is pale or sandy, some jaguars are all brown or black (eg panthers), but their markings are always faintly evident. Sadly, these beautiful markings are one of the reasons these cats are persecuted by humans and poached for their pelts – as well as for their teeth, paws and several other parts.

All big cats have powerful muscles, which help them chase down prey, but are also handy for climbing trees where jaguars spend much of the day asleep. This apex predator tends to hunt and feed alone at night in the swamps, grasslands and forest of the Amazon, using stealth and ambush tactics to catch quarry.

As much of the jaguar's home has been eliminated to make way for cattle ranches and crops, these normally covert cats have been forced out into the open. Their natural prey – including peccaries and turtles – are also dwindling. As a result these cats have developed a new taste for the more abundant cattle. By venturing out of cover, the jaguars leave themselves exposed to ranchers who view these amazing animals as pests. Jaguars will also often have to cross vast distances in search of their next meal, which brings them near to other dangers like roads and traps.

To safeguard the future of this remarkable creature, a project has been set up to conserve the jaguars' safe passage from Argentina to Mexico. Called the Panthera Jaguar Corridor Initiative, it involves governments and conservation organisations as well as local communities making sure jaguars can travel from one wild region – through human-inhabited areas – to another. Activities include finding the safest and most beneficial corridor routes for the cats to take; educating local communities; and monitoring jaguar numbers as well as their prey populations.

The statistics...



Jaguar

Binomial: Panthera onca

Type: Mammal

Diet: Carnivore (eg caimans, capybaras, turtles)

Life span in the wild: 12-15 years

Length: 2.2m (7.2ft)

Weight: 45-115kg (99-254lb)

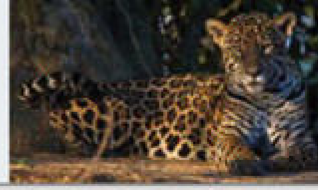
Height: 0.7m (2.2ft)

There are thought to be some 2,000 jaguars living in the rainforests of Central America

STRANGE BUT TRUE
FELINE FROLICS

What activity do jaguars like to do for fun?

A Go for a swim **B** Moonwalk **C** Hunt in packs



Answer:
Unlike most of the feline family, jaguars delight in playing and hunting in water. They are aquatic cats and appear to really enjoy stalking turtles and caimans in marshy ponds, using their paws to feel around for them in the murky water.

DID YOU KNOW? As well as spraying scent from a gland below the tail, jaguars also have scent glands in their cheeks

Along with tigers, jaguars are unusual in that they enjoy swimming – even if this one doesn't seem too happy!

Learn more

To find out more about Panthera's Jaguar Corridor Initiative, you can read our interview with the organisation's CEO, Alan Rabinowitz, over on pages 8-9.

"In the period of dormancy that follows, rain and snow gather in the basin to create a deep body of water"

Located in Honshu, Japan, Mount Zao's crater lake is sometimes called Five Colour Pond as it changes hues according to the weather

How crater lakes form

HIW dives in to the geology behind these bodies of water with an explosive past

When you look out across a mountain lake it can be easy to think it was always so serene, but this couldn't be further from the truth. From the shifting of Earth's tectonic plates to glaciers gouging out the land, the majority of these tranquil sites are the result of epic geological events.

Crater lakes have perhaps the most epic beginnings of them all. While maar lakes are also the result of volcanism, forming in the fissures left behind by ejected magma, they are generally quite shallow bodies of water; indeed, the planet's deepest – Devil Mountain Maar in Alaska – is 200 metres (660 feet) from surface to bed. In terms of scale, maars aren't a patch on their bigger cousins.

Crater lakes have very violent origins. During a mega-eruption, or series of eruptions, the terrain becomes superhot and highly unstable. In some cases the volcanic activity is so intense that once all the ash and smoke clears, the cone is revealed to have vanished altogether, having collapsed in on itself. This leaves a massive depression on the top of the volcano known as a caldera.

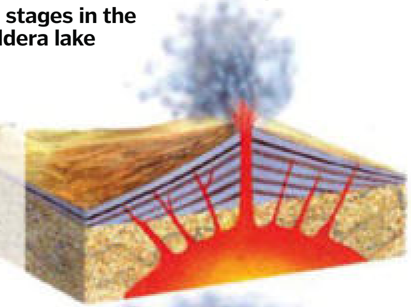
In the period of dormancy that follows, rain and snow gather in this basin, generally over several centuries, to create a deep body of water; Crater Lake in Oregon is the deepest of any lake in the USA, plunging to 592 metres (1,943 feet). Over time a caldera lake will reach a perpetual level that's maintained by a balance of regional precipitation and annual evaporation/seepage.

Crater lake in the making

We pick out four key stages in the development of a caldera lake

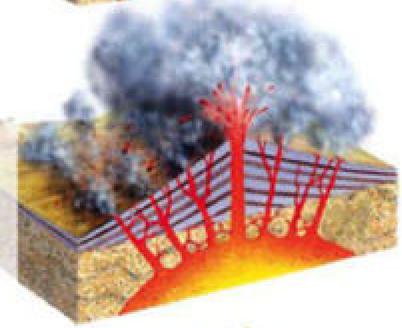
1. Volcano

All volcanoes feature a crater to some extent at their peak, but lakes rarely get the chance to form because of geothermal activity.



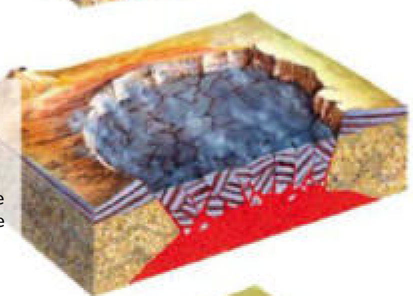
2. Mega-eruption

If a volcano has lain dormant for a long time, or if there is dramatic tectonic activity, a much bigger eruption than normal might occur.



3. Collapse

Such a climactic event at the very least expands the size of the crater, however in more extreme cases the volcano's entire cone collapses inwards to leave a caldera.



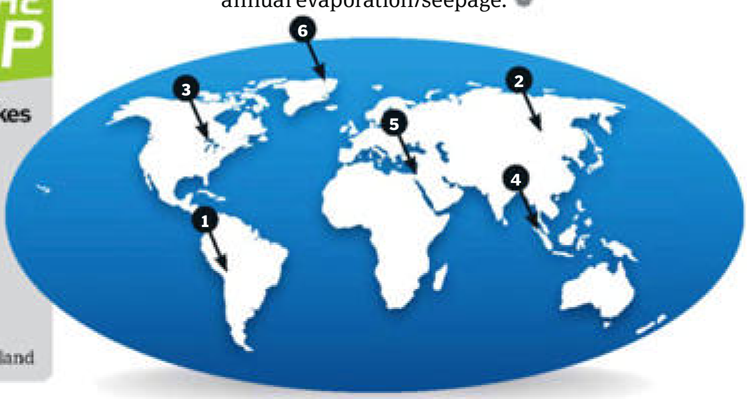
4. Lake

Over centuries, the magma chamber below the caldera turns solid. In the cooler basin, rain and snow have an opportunity to build up and form a lake.

ON THE MAP

Record-breaking lakes

1 Highest navigable lake: Titicaca, Peru/Bolivia
2 Deepest: Baikal, Russia
3 Biggest lake group: Great Lakes, USA
4 Largest crater lake: Toba, Indonesia
5 Lowest: Dead Sea, Israel/Jordan
6 Most northerly: Kaffeklubben Sø, Greenland



Some like it hot...

Volcanic activity can continue to simmer under the crater, which affects the chemistry of the lake. A lack of productivity often means the water is very clear, hence why jewel-like greens and blues are common. This doesn't mean crater lakes are barren though. Some are a lot more hospitable than others, supporting insects, fish, right through to apex predators. But even ones spewing out deadly gases and minerals can still support ecosystems. For instance, the water of hyper-alkaline (pH 11) Laguna Diamante in the Andes contains arsenic and is five times saltier than seawater, but a research team in 2010 found 'mats of microbes' living on the lake bed, which served as food for a colony of flamingos.

"In the year-round warm and wet conditions, plants can grow, flower and fruit nonstop"

Multistorey life in the rainforest

The rainforest is a three-dimensional world, with multiple levels of wildlife up its towering trees

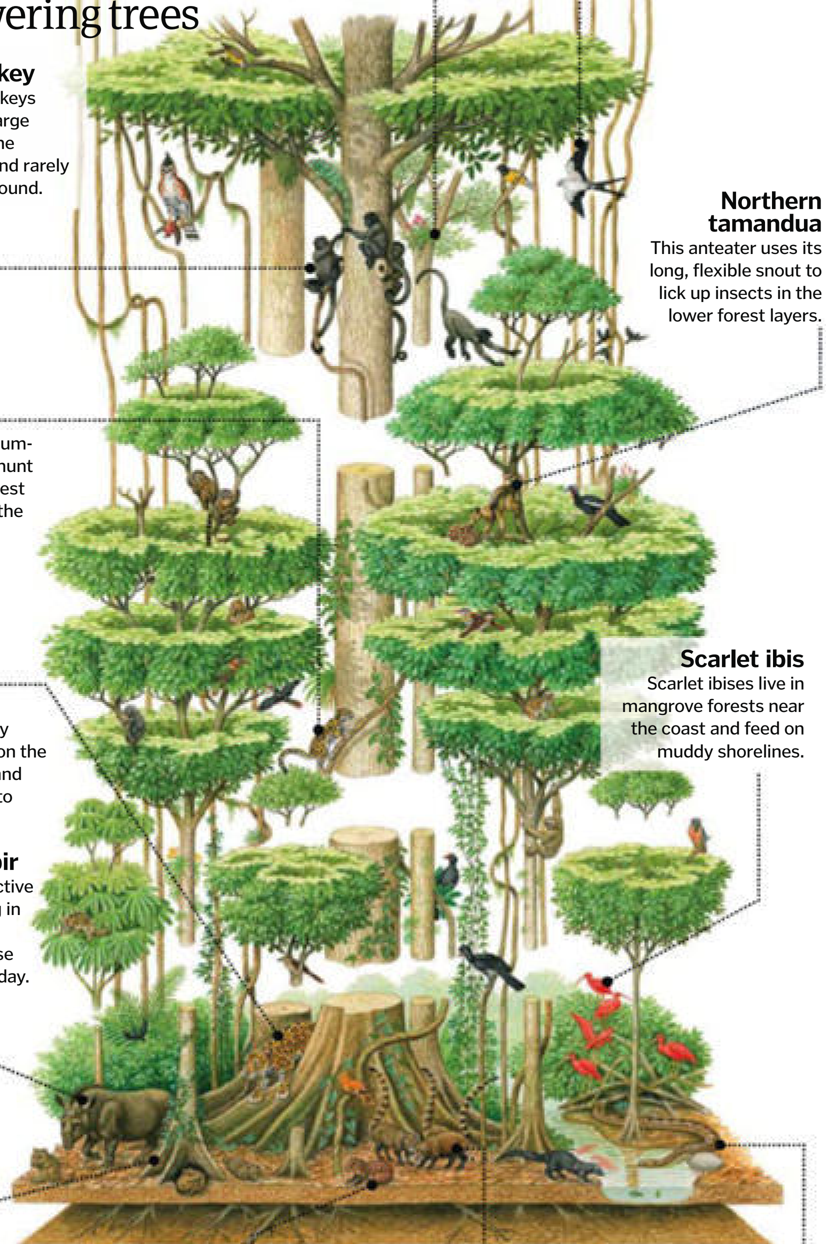
Tropical rainforests are incredibly rich in wildlife. They cover about two per cent of Earth's surface, yet they are home to around half of all the known species of flora and fauna. In the year-round warm and wet conditions, plants can grow, flower and fruit nonstop. That allows trees to quickly reach great heights. In a typical rainforest, the treetops overlap to form a continuous green layer called the canopy, about 45 metres (150 feet) above ground level. A few trees, called emergents, project well above this canopy – the tallest reaching over 80 metres (260 feet) high.

The dense canopy of leaves blocks most sunlight from reaching the ground, where it is shady, damp and dank. For a visitor expecting to see a jungle full of colourful birds and monkeys, the rainforest floor is disappointing. A few small mammals do scurry about here, feeding on fruit that's dropped from above, but they are mostly shy and secretive. Wild cats, like ocelots and jaguars, hunt them – mainly at night – but these are even more difficult to spot.

Life on the forest floor is mostly small and hidden. Dead animals, broken branches and even whole trees from above are the food for myriad insects, worms and fungi. Along with bacteria, these decomposers play a vital role, quickly breaking down the detritus and releasing minerals and nutrients back into the soil to nourish new life in a perpetual cycle.

Meet the low life

The lower storeys of the rainforest are leafy and shady, but jam-packed with hidden life



Epiphytic orchid
9,000 species of orchid live as epiphytes – growing on the platform of a branch, but extracting nothing from the tree like a parasite.

Swallow-tail kite
This agile bird of prey soars above the canopy, searching for reptiles sunning on branches, then swoops in to snatch them.

Woolly monkey
These noisy monkeys travel by day in large troops through the middle canopy, and rarely venture to the ground.

Northern tamandua
This anteater uses its long, flexible snout to lick up insects in the lower forest layers.

Ocelot
Ocelots are medium-sized cats. They hunt mainly on the forest floor, and spend the day well-hidden asleep in trees.

Jaguar
Jaguars are shy, solitary and rarely seen. They hunt on the rainforest floor, and climb trees only to escape danger.

Scarlet ibis
Scarlet ibises live in mangrove forests near the coast and feed on muddy shorelines.

Brazilian tapir
Tapirs are only active at night, foraging in swampy terrain. They hide in dense undergrowth by day.

Rainforest fungi
Rainforest fungi produce a spreading network of fine threads to decompose dead wood. These 'mushrooms' are their spore-producing fruiting bodies.

Poison-arrow frog
Bright colours warn predators that these amphibians are deadly. Native Indians use the poison to tip their arrows.

Buttress root
Tree roots get little grip in thin rainforest soils, so many trees also have massive buttress roots to help prop them up.

Paca
A species of agouti (a rodent), the paca has strong enough jaws to open brazil nut fruit and release their seeds.

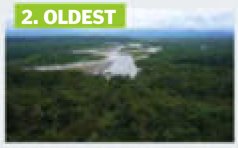
Coati
Coatis move in groups across the forest floor. They climb to mid-level in the trees, using their tails for balance.

Anaconda
This huge snake lives near rivers and swamps, hunting reptiles and small mammals, which it coils around to kill.

1. LONGEST

Common anaconda

This snake often reaches ten metres (33 feet) long. The reticulated python can be equally long, but the anaconda is bulkier.



2. OLDEST

Amazonian rainforest trees

A recent study showed that many trees in the Amazon are over 300 years old. Some even reach grand ages of 750-1,000 years.

3. HEAVIEST

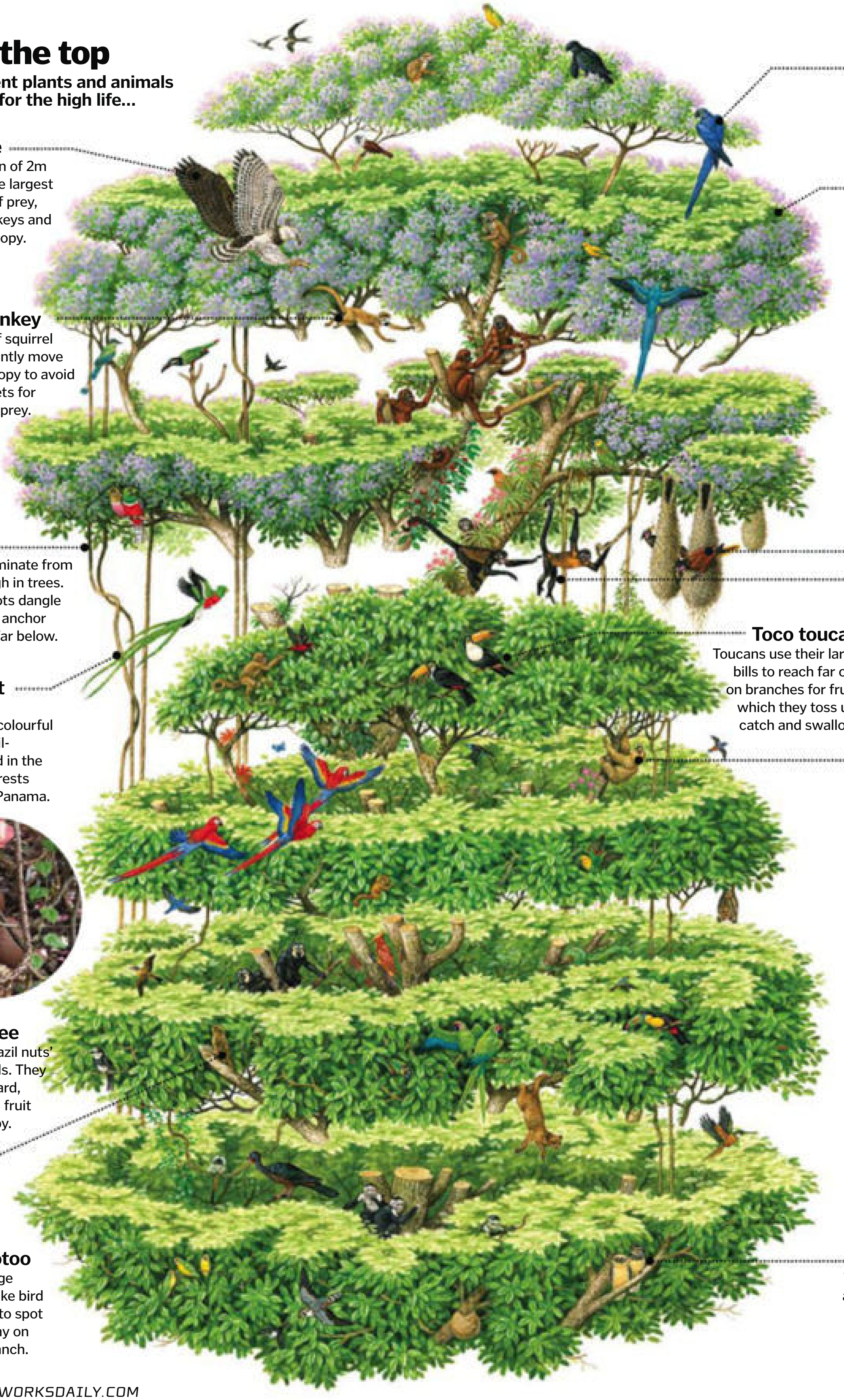
African elephant

Elephants in central Africa sometimes move from the open savannah into dense rainforests. They can weigh up to ten tons.

DID YOU KNOW? *A football pitch-sized area of rainforest can hold 480 species of tree; a European forest might have just six*

Life at the top

Many different plants and animals are adapted for the high life...



Harpy eagle

With a wing span of 2m (6.6ft), this is the largest rainforest bird of prey, feeding on monkeys and sloths in the canopy.

Squirrel monkey

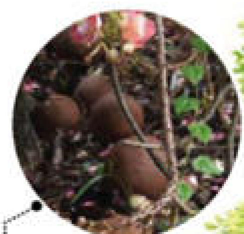
Family groups of squirrel monkeys constantly move through the canopy to avoid being easy targets for passing birds of prey.

Liana

These vines germinate from seeds lodged high in trees. Their feeding roots dangle down in order to anchor them in the soil far below.

Resplendent quetzal

The quetzal is a colourful bird with long tail-streamers, found in the canopy of rainforests from Mexico to Panama.



Brazil nut tree

What we call 'brazil nuts' are actually seeds. They develop inside hard, cannonball-sized fruit in the mid-canopy.

Common potoo

Clever camouflage makes this owl-like bird near-impossible to spot as it sleeps by day on top of a dead branch.

Blue-and-yellow macaw

These large members of the parrot family fly in flocks of up to 20, searching the canopy for ripe fruit.

Flowering tree

In tropical rainforests, some trees flower and others produce fruit all year, ensuring plentiful food for the many animals.

Crested oropendola

The pouch-like nests of these birds are a distinctive feature, dangling in groups from the ends of branches near rivers.

Spider monkey

Spider monkeys sometimes hang on their prehensile tails as they forage for fruit and nuts high in the canopy.

Toco toucan

Toucans use their large bills to reach far out on branches for fruit, which they toss up, catch and swallow.

Three-toed sloth

Algae growing on the fur of slow-moving sloths give them a greenish colour which helps camouflage them amid the foliage.

Epiphytic bromeliad

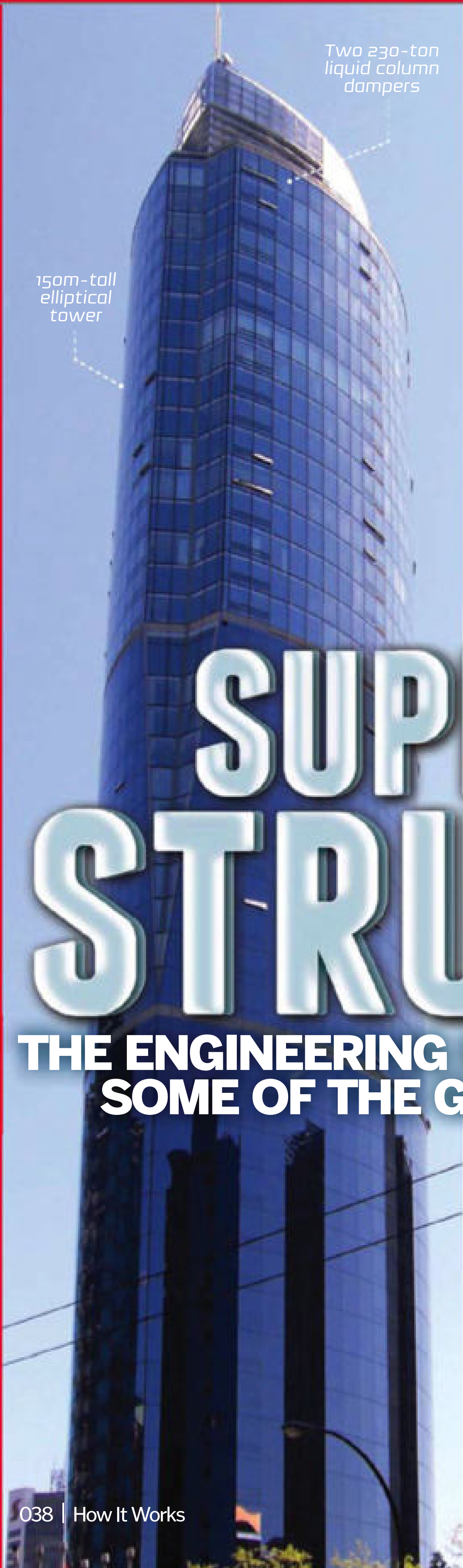
Epiphytes, like this bromeliad, are sometimes called air plants because they grow in 'mid-air', with no connection to the soil.

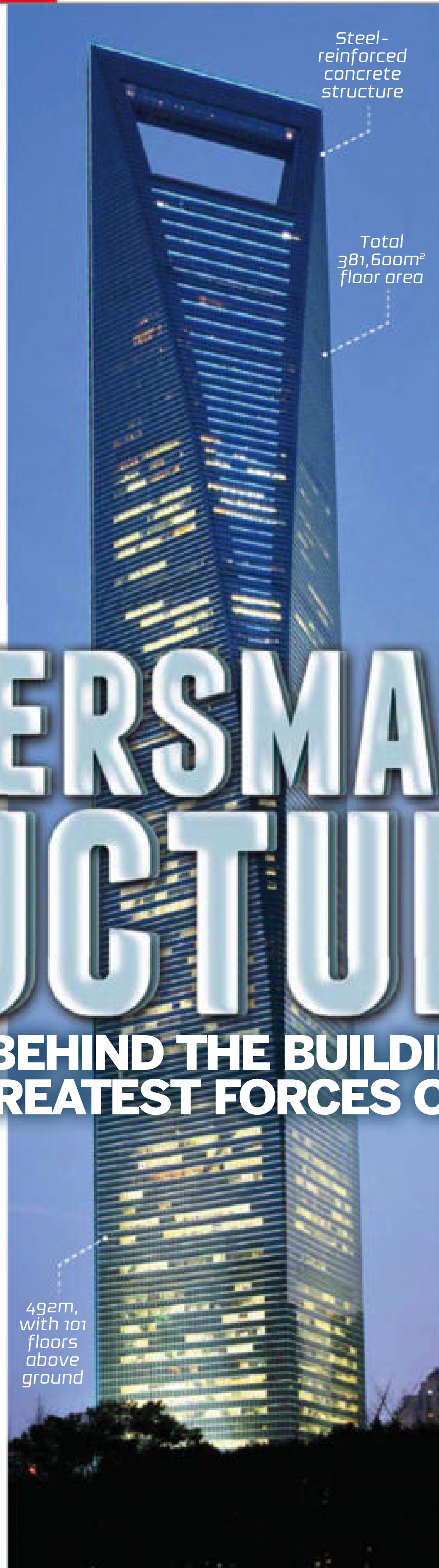
Spectacled owl

These birds hunt at night among forest trees. They communicate with calls that sound like someone shaking metal sheeting.

SUPERSMART STRUCTURES

THE ENGINEERING BEHIND THE BUILDINGS DEFYING SOME OF THE GREATEST FORCES OF NATURE





5 TOP FACTS
TOUGH BUILDINGS

Petronas Twin Towers
1 The Skybridge connecting the towers at the 41st and 42nd floors of this Malaysian landmark isn't fixed at either end. It slides in and out as the towers sway in the wind.

The Bubble Houses
2 This pair of dome houses in Florida were built in 1954 by architect Eliot Noyes. They use no wood or nails and their domed shape makes them great at resisting hurricanes.

US Bank Tower
3 The tallest building in California, this office block in LA is designed to withstand an 8.3-magnitude earthquake – larger than the San Andreas Fault can generate, in theory.

Nishiki Tower
4 A five-storey, tsunami-proof building in Japan, containing rescue equipment and space for evacuees to shelter. It could withstand an impact from a ten-ton ship!

County Records Building
5 Built in 1827 in Charleston, South Carolina, it's the oldest fireproof building in the USA. It's constructed entirely from solid masonry to protect the valuable county records.

DID YOU KNOW? *The Taipei 101 skyscraper can boast the world's fastest lifts; they travel at 60.7km/h (37.7mph)!*

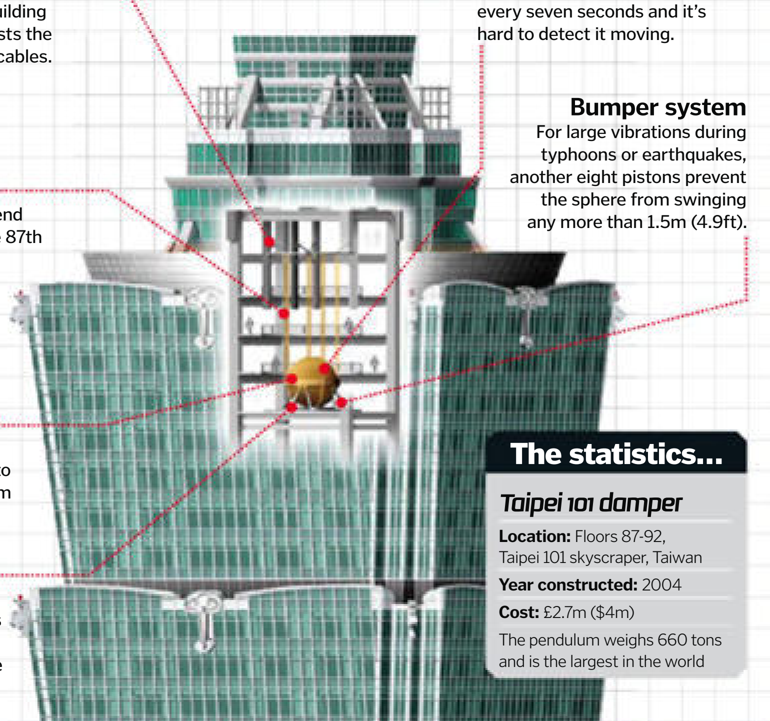
After a tsunami hit Japan in 2011, a 27-metre (89-foot)-long boat was left perched on the roof of a two-storey building. Although almost every other nearby structure had been flattened, this particular building had survived both the wave and the weight of the vessel on top. It was a hostel in the town of Otsuchi, made of concrete blocks with a flat roof. When the tsunami struck, the water swept through the ground floor foyer and knocked down some of the walls, but the supporting corner pillars survived and, as a result, the building stayed up. The houses around it were made of timber and the wave simply ripped them from their foundations.

In this modern version of *The Three Little Pigs* story the house with the best design is the one that stays upright. But in the 21st century, buildings have a lot more to contend with than hungry wolves. There are now nine buildings in the world that are over half a kilometre tall with more planned or currently under construction. At that height, winds cause skyscrapers to sway from side to side by up to two metres (6.6 feet) on the top floors. From below, earthquakes can vibrate the ground to such an extent it turns to quicksand, causing buildings to pull loose from their foundations and topple clean over. Fortunately today's architects have more than straw, sticks and bricks at their disposal…

Counteracting the wind

Because they are anchored at the bottom and free at the top, tall buildings sway in the wind. Skyscrapers can defend against this by making themselves stiffer, but only up to a point as stiffer materials are more prone to cracking. Sometimes it is better to design the building with some flexibility and to avoid harmonic frequencies that could exaggerate the movement. Dubai's Burj Khalifa uses a deliberately irregular, stepped shape to break up wind vortices, while others like the Taipei 101 use tuned mass dampers – giant hydraulic pendulums hung near the top – that swing to counterbalance sway from the wind. Low-rise buildings aren't safe either. In a hurricane, pitched roofs act like an aerofoil as wind passes over them, sucking them upwards. Hurricane-proof houses use steel struts or cables that run through the walls to bind the roof to the foundations.

Taipei 101 in focus



Tuning frame
On the 91st floor, a support frame monitors building vibration and adjusts the movement of the cables.

Movement range
Normally, the sphere swings no more than 35cm (13.8in) every seven seconds and it's hard to detect it moving.

Bumper system
For large vibrations during typhoons or earthquakes, another eight pistons prevent the sphere from swinging any more than 1.5m (4.9ft).

Steel cables
Eight cables descend 42m (138ft) to the 87th floor. Each is 9cm (3.5in) thick and could support the mass damper by itself.

Mass block
41 steel plates are stacked together to form a sphere 5.5m (18ft) across.

Hydraulic dampers
Eight huge pistons absorb the energy of the steel sphere as it swings from its cables.

The statistics…
Taipei 101 damper

Location: Floors 87-92, Taipei 101 skyscraper, Taiwan

Year constructed: 2004

Cost: £2.7m ($4m)

The pendulum weighs 660 tons and is the largest in the world

Tackling tsunamis

A tsunami occurs when an earthquake lifts or drops a section of seabed. Although the vertical movement might be less than a metre (3.3 feet), it is many miles wide and involves billions of tons of water. Out at sea, tsunamis travel as fast, low waves, but when they reach the shore, the wave front can rise to 30 metres (98 feet), travelling inland for up to five kilometres (3.1 miles). Just two metres (6.6 feet) of water exerts enough pressure to destroy a brick wall, and boats, cars and debris carried with it strike buildings with the force of a wrecking ball. Buildings can also be destroyed as water scours away at the soil and undermines foundations.

Rather than trying to stop the water, tsunami-proof buildings present as little resistance to its flow as possible. The walls of the ground floor may be designed to fall down, while the upper storeys are supported by strong pillars at each corner – or the entire building may be on stilts. It is also more effective to place houses at a 45-degree angle with large gaps between them. Artificial reefs can absorb a lot of the wave energy before it hits land.

The statistics…
Tohoku Sky Village

Location: North-east Japan

Year constructed: Proposed

Cost: £160 million

SAKO Architects has designed a circular platform 20m (66ft) above sea level with room for up to 500 houses. If a tsunami strikes here, the whole village becomes an artificial island

Fighting fire

Concrete and brick are both already fireproof, but buildings *made* of brick or concrete are not. A steel-framed building will collapse once flames reach in the region of 540 degrees Celsius (1,004 degrees Fahrenheit) because the steel becomes soft. Building fires can reach these temperatures quite quickly, feeding on nothing more than the furniture and fittings.

Sometimes the best solutions are surprisingly low tech. Ordinary plasterboard is made of the mineral gypsum, which has water chemically locked up within it. When it gets hot, this water is released as steam, which absorbs some of the heat from the inferno. Similarly, steel beams can also be protected by spraying them with a quick-setting gypsum mixture.

To prevent fire from spreading through cable ducting and access channels, we use something known as intumescent materials that swell when they are heated. Packed around a plastic pipe, for instance, an intumescent foam will pinch the pipe shut, sealing it.

The statistics…
Gotthard Base Tunnel

Location: Swiss Alps

Year constructed: Due to open 2016

Cost: £6.9b ($10.4b)

Temperatures above 1,000°C (1,832°F) cause reinforced concrete to collapse, but a special fire-resistant coating will withstand 1,400°C (2,552°F) for up to 90 minutes

> "Halochromic paints change colour if the underlying metal begins to rust"

Concrete has been used since Ancient Roman times, but the modern version comes in a lot of exciting new flavours. Concrete can be made extra light, extra dense, springy, translucent and even self-healing, while glass can be shatterproof, load bearing and heatproof. And there are totally brand-new materials too…

Magnetorheological fluid normally behaves as a liquid, but in a magnetic field it stiffens to become solid. Pistons filled with this wonder fluid can act as dynamic shock absorbers with great strength and lightning-fast responses. Previously this was the preserve of high-tech vehicle suspensions, but engineers are now starting to use magnetorheological dampers to control earthquake vibrations in tall buildings. Halochromic paints change colour if the underlying metal begins to rust. This tech is still being trialled for use on aircraft, but one day could warn if a bridge needs repainting.

Fire is a threat to all buildings but the danger is particularly acute in skyscrapers. However many storeys you stack on top of each other, everyone still has to evacuate via the ground floor. The Burj Khalifa has over 160 floors and so taking the stairs all the way down just isn't practical. Instead the elevators feature water-resistant equipment, redundant power supplies and drainage sills to keep water from the sprinklers out of the lift shafts. If you do need to take the stairs, there are pressurised, air-conditioned refuge areas every 25 floors to allow evacuees to rest and the stairwells are built from highly fire-resistant concrete.

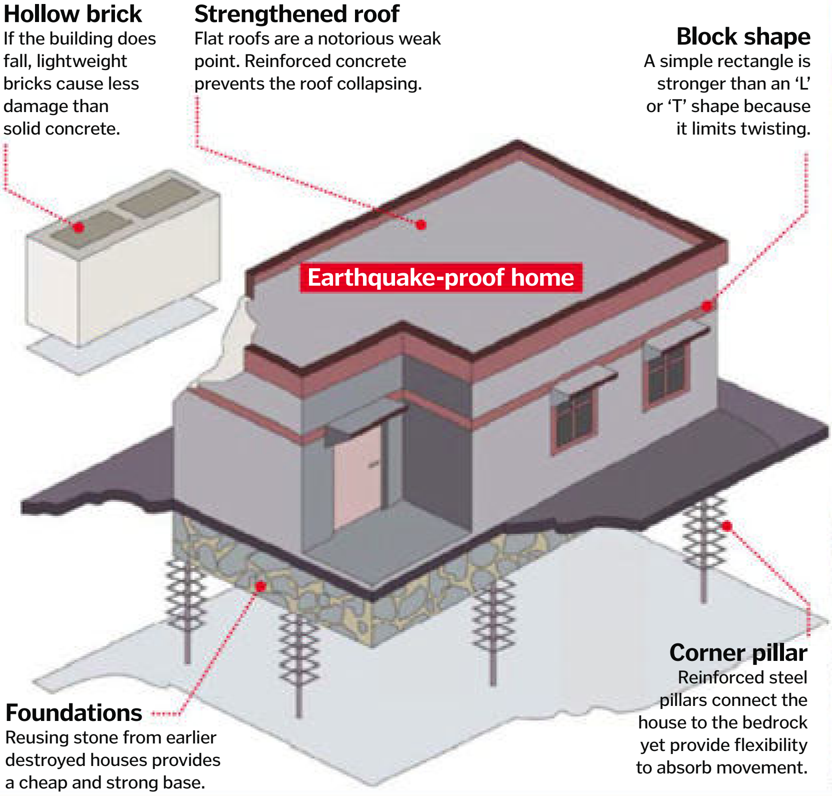
In 1956 the architect Frank Lloyd Wright proposed the Mile High Illinois Sky-City. A steel-framed building 1,600 metres (5,250 feet) tall would have swayed far too much using the construction techniques of the time, and the lift shafts would have taken up all the space on the upper floors, so the project was scrapped.

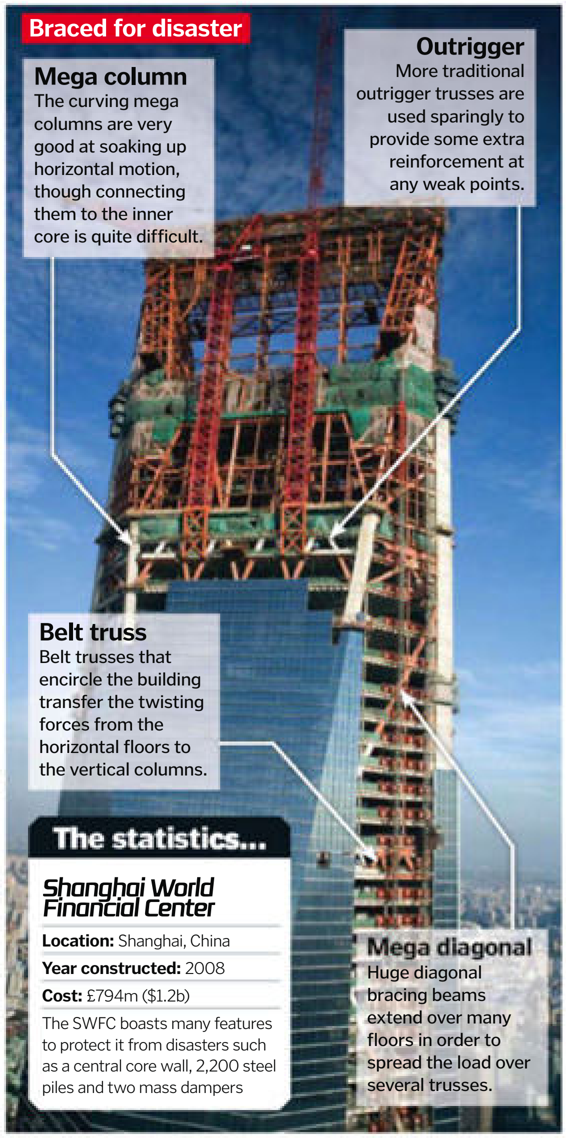
However, materials, techniques and technology have all come on leaps and bounds since then and a lot of the practical problems have now been solved. The Burj Khalifa is already more than half the height of Lloyd Wright's science-fiction design and human ingenuity shows no signs of slowing down.

Staying steady in an earthquake

Most office buildings and skyscrapers are built with floors and roofs resting atop wall pillars. Their strength comes from the huge weight pressing down. But this strength is a vulnerability in an earthquake as the floors collapse in on themselves. For medium-sized buildings, the best way to quake-proof them is to cut down on the weight. Lighter roofs and floors lower the peak stresses during an earthquake, while constructing concrete floors by pouring them in situ bonds them to the walls.

Some skyscrapers have huge roller bearings in the foundations that allow the whole building to slide without cracking. Tuned mass dampers can also be used to counter quakes.





£157bn

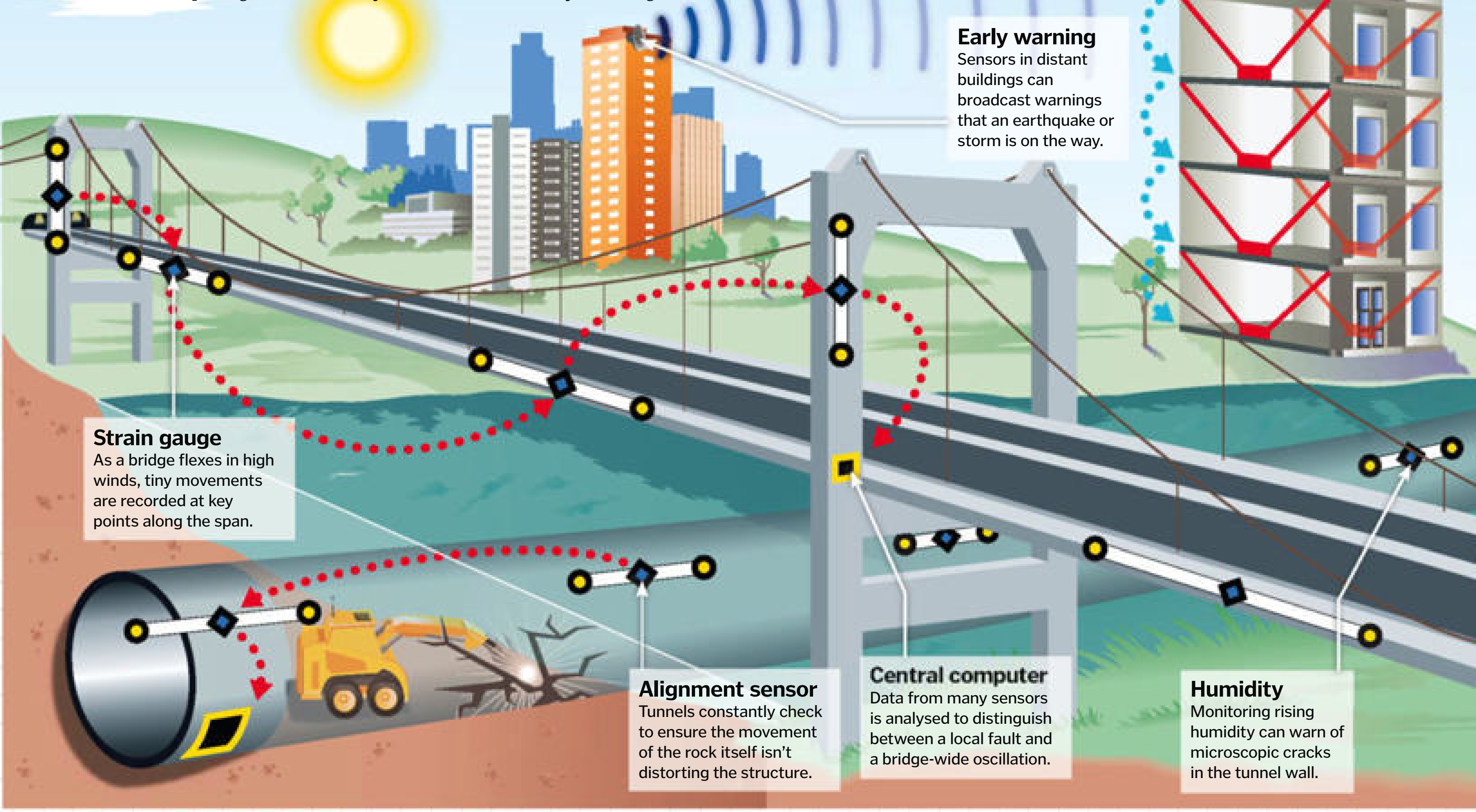
MOST EXPENSIVE EARTHQUAKE

The 2011 magnitude-9 earthquake and tsunami that struck Japan was the costliest natural disaster in recorded history. 129,225 buildings were completely destroyed and almost a million more were damaged.

DID YOU KNOW? *The emergency fire sprinkler system in the Burj Khalifa uses 213km (133mi) of piping!*

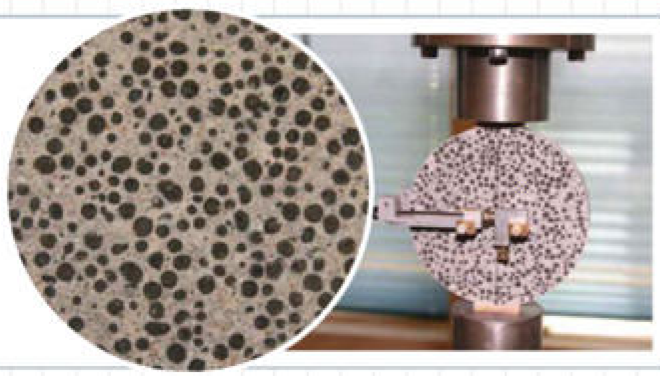
Sensing disasters before they happen

Sensors are very cheap compared to the cost of a skyscraper or a suspension bridge, but their valuable information could save lives. Accelerometers provide the raw data to control the swing in the mass damper pendulums of some skyscrapers. But even when the building can't react immediately, sensors are still vital. The strain gauges on a bridge can detect dangerous harmonic oscillations before they get out of control. This allows the bridge to be shut and helps engineers find tiny cracks that might otherwise be missed. Sensors don't operate in isolation. Wired and wireless networks connect them to computers that analyse patterns. If sensor A records a movement and milliseconds later sensor B records the same movement, it shows a vibration passing through the building. This data can even be passed from one building to another, allowing smart structures to interact and send out early warnings.



Concrete is getting clever

Building smart structures isn't just about attaching microcomputers; sometimes the technology is embedded in the actual building materials. Reinforced concrete is strengthened with steel bars, but steel isn't the only thing you can add to concrete. Adding plastic fibres with a special nonstick coating makes concrete as springy as wood. Alternatively adding optical glass fibres that run from one side to the other lets enough light through to make concrete translucent; that's not just attractive – translucent concrete can let you spot cracks deep within a block. But the ultimate building material doesn't just reveal cracks, it repairs them. A team in the Netherlands is developing concrete which has tiny capsules of special bacterial spores embedded in it (pictured). Any water that seeps in through hairline cracks reactivates the dormant spores. As they reanimate, they produce limestone as a by-product, which seals up the cracks.



"Water decreases in density as it gets warmer and rises to an outlet at the top of the tank"

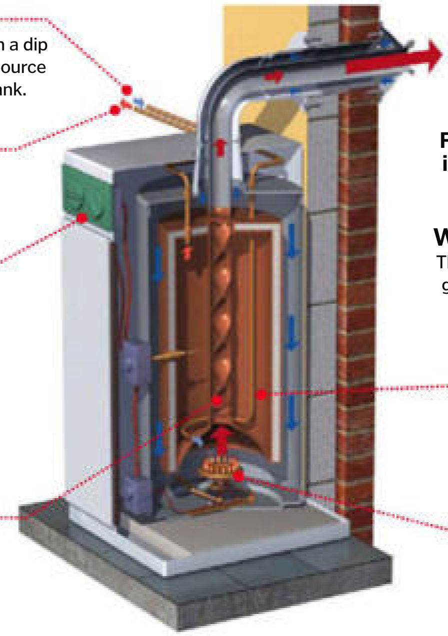
Inside a domestic water heater

The technology that provides the luxury of a hot bath…

Like hot-air balloons, domestic water heaters rely on the principle that warm things rise. When a tap is turned on in a house, unheated water flows through a tube leading to the bottom of a large steel storage tank. As the tank fills up, electrical heating elements, or a burner at the bottom fuelled by oil or gas, warm the water to a temperature controlled by a thermostat. Water decreases in density as it gets warmer and rises to an outlet at the top of the tank that is connected to the hot water taps. Cooler, denser water naturally sinks below the warmed water to the base of the tank and is heated up. A cycle is thus created that keeps hot water flowing while the heater is on and water is in the tank. Unused water stays warm in the tank for some time because of insulation in the lining.

Conventional tank-type water heater

Find out what's happening in that tank in the closet…



Inflow
Cold water enters through a dip tube and flows to a heat source at the bottom of a steel tank.

Outflow
As its density decreases, warm water rises up to an outflow pipe and from there supplies hot water taps.

Thermostat
The temperature of the water is maintained by setting a thermostat that switches the heater on or off as required.

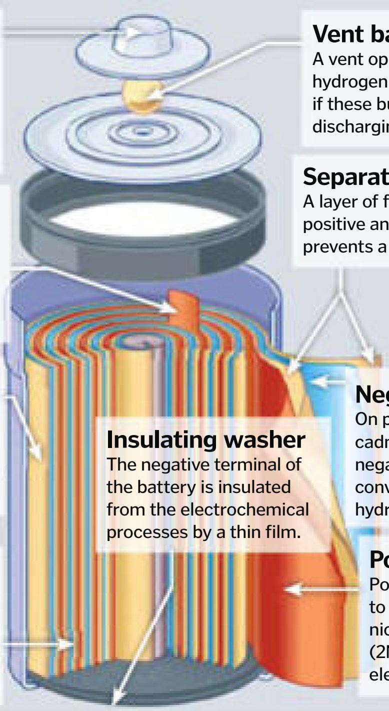
Exhaust flue
Gases produced during combustion in gas-fuelled water heaters have to be vented.

Water storage tank
The steel tank is lined with glass to prevent corrosion and is insulated to keep water warm for longer.

Heat source
Cold water is heated by electrical elements or a burner fuelled by oil, propane or another gas.

Rechargeable cells

How do nickel-cadmium batteries keep portable devices going and going?



Positive terminal
Power discharges when a device creates a circuit that lets electrons flow from the negative to the positive terminal.

Positive tab
Electrons move from the positive terminal to the positive electrode during power discharge, or vice versa during recharging.

Electrolyte
Electrical charge is conducted to and from the positive and negative electrodes via a potassium hydroxide (KOH) solution.

Jelly roll
The positive and negative electrodes, with a separator in between, are wound into a cylindrical spiral inside the battery.

Vent ball
A vent opens to release hydrogen or oxygen gas if these build up during discharging and recharging.

Separator
A layer of fabric in between the positive and negative electrodes prevents a short circuit.

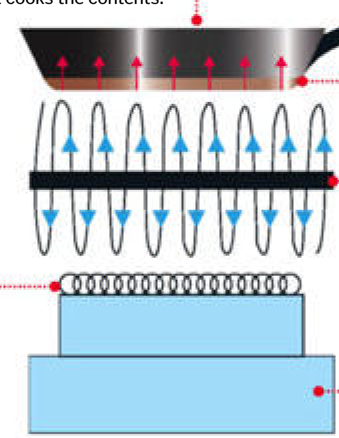
Insulating washer
The negative terminal of the battery is insulated from the electrochemical processes by a thin film.

Negative electrode
On powering a device, cadmium (Cd) in the negative electrode is converted to cadmium hydroxide ($Cd[OH]_2$).

Positive electrode
Powering devices leads to the conversion of nickel hydroxide (2NiOOH) in the positive electrode to $2Ni(OH)_2$.

How induction hobs heat food

The secret of the hotplate that isn't hot to the touch



Food
Kinetic energy from collisions between electrons and ions in the pan base is released as heat that cooks the contents.

Pots and pans
When a pan with a magnetic base is on the hob, the magnetic field moves electrons in the metal.

Hob surface
The hob surface doesn't radiate heat but provides a base on which a pan can sit within the magnetic field.

Induction coil
Current passing through the copper wire generates an alternating magnetic field at the surface of the hob.

Power supply
Electrical current is supplied through a stream of electrons to a coil of copper wire under the hob.

"Uses for 3D printers are varied, with applications in the military, medical, industrial and commercial spheres"

3D printers explored

How do these clever machines take printing to another dimension and what is their potential for the future?

3D printing is the manufacture of a physical three-dimensional object by the layering of two-dimensional cross sections, one on top of the other. The layers are fabricated through the solidifying and binding of a build material – such as polylactic acid (PLA) – from a liquidised/powder state, with a series of heaters, nozzles and cooling units. The result of this cross-sectional layering is that solid and hollow items can be created by simply inputting the desired object's dimensions into the 3D printer.

The design schematics for 3D printer models come from computer-aided design (CAD) files, with a virtual model parsed into thousands of cross sections, which become instructions for the printer's control units. This data dictates exactly where to deposit the material in each layer, with the process taking place on a stable, non-stick surface called the build plate.

Uses for 3D printers are extremely varied, with applications in the military, medical, industrial and commercial spheres. A good example of this is the use of 3D printing in the prototyping of new machine components. Here complex designs for intricate parts can be quickly and cheaply constructed out of biodegradable plastic, trialled in a test machine and then tweaked if necessary.

While previously 3D printing has largely been confined to large-scale operations due to high cost, in the last five or so years desktop 3D printers aimed at enthusiasts have emerged. These allow anyone to feed a printer with designs from their PC – banks of online designs exist – or a memory card, and make models at home. One such DIY printer is the MakerBot: Replicator 2, which we look at closely here.

History of 3D printing

HIW reveals how this industry has come on leaps and bounds over the past few decades…

1976
Inkjet is born
The inkjet printer's invention opens up the possibility of printing objects through layering a liquefied material.

1984
Chuck goes stereo
American engineer Charles 'Chuck' Hull invents stereolithography, a printing process that allows 3D objects to be created from digital data.

1992
Prototype
Charles Hull's company 3D Systems makes the first commercial stereolithographic 3D printing machine.

1993
MIT
Scientists working at the Massachusetts Institute of Technology (MIT) first coin the term '3D printing'.

2002
Printing organs
Scientists use 3D printing technology to engineer a miniature but functional kidney that is able to filter blood. Organ printing takes off.

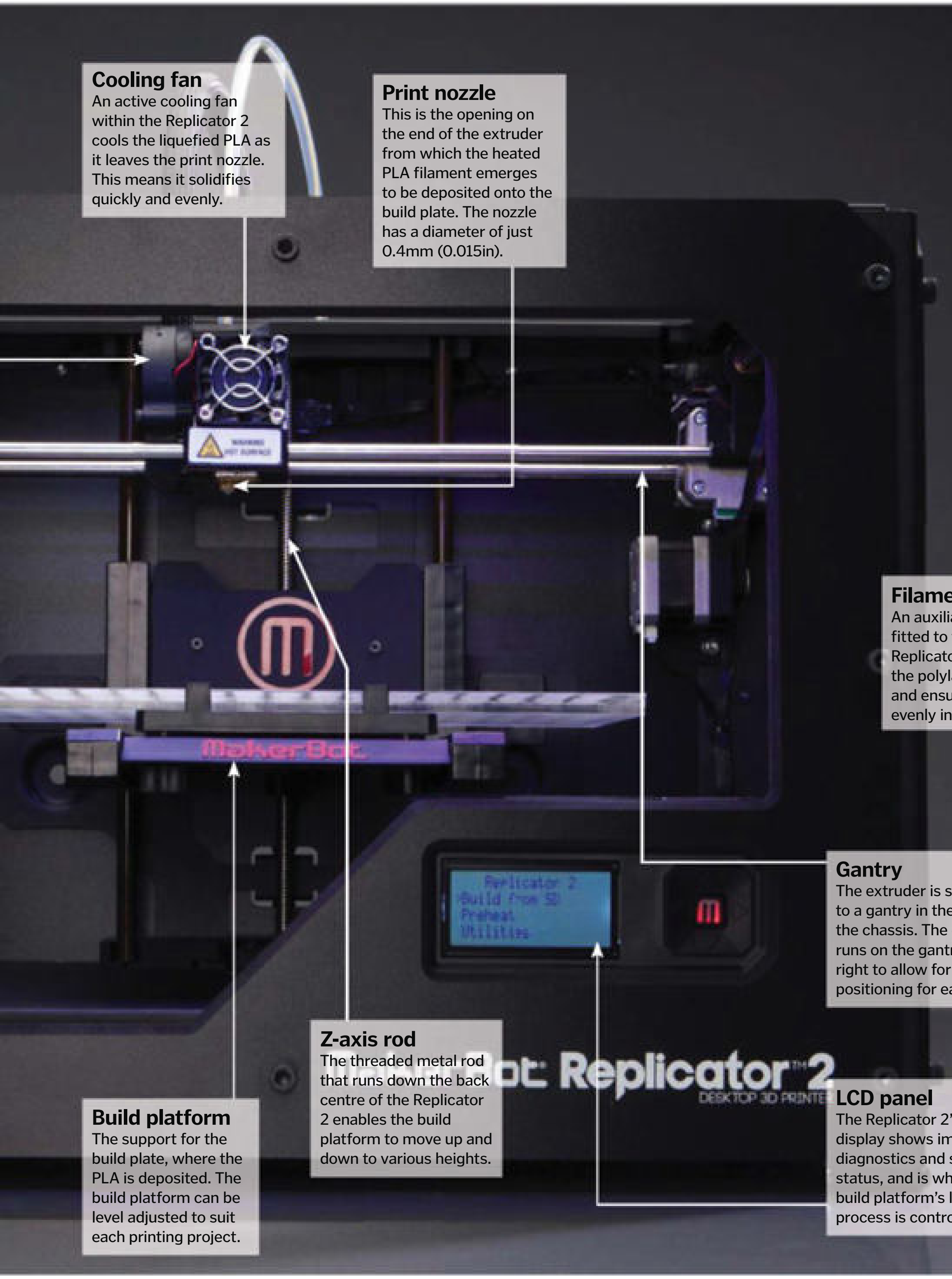
AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

See a bust made of MakerBot CEO, Bre Pettis

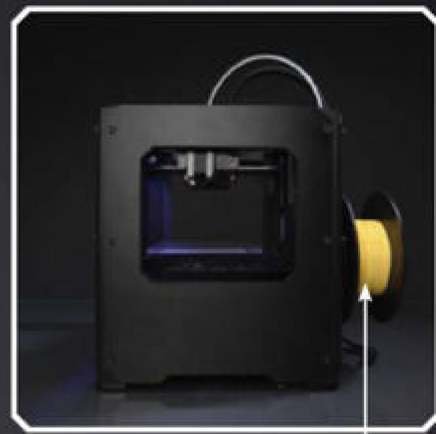
www.howitworksdaily.com

DID YOU KNOW? *In February 2013 plans for a structure on the Moon built in part by 3D printers were revealed*



Replicator 2 up close

What technology enables this printer to produce objects in three dimensions?



Cooling fan
An active cooling fan within the Replicator 2 cools the liquefied PLA as it leaves the print nozzle. This means it solidifies quickly and evenly.

Print nozzle
This is the opening on the end of the extruder from which the heated PLA filament emerges to be deposited onto the build plate. The nozzle has a diameter of just 0.4mm (0.015in).

Filament spool
An auxiliary spool that is fitted to the rear of the Replicator 2. This holds the polylactide filament and ensures it is fed evenly into the extruder.

Gantry
The extruder is secured to a gantry in the top of the chassis. The extruder runs on the gantry left to right to allow for precise positioning for each layer.

Z-axis rod
The threaded metal rod that runs down the back centre of the Replicator 2 enables the build platform to move up and down to various heights.

LCD panel
The Replicator 2's LCD display shows important diagnostics and system status, and is where the build platform's levelling process is controlled.

Build platform
The support for the build plate, where the PLA is deposited. The build platform can be level adjusted to suit each printing project.

The statistics...

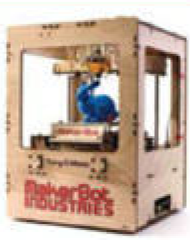
MakerBot Replicator 2

- **Height:** 38cm (14.7in)
- **Width:** 49cm (19.1in)
- **Depth (no spool):** 32cm (12.8in)
- **Weight:** 11.5kg (25.4lb)
- **Operating temperature:** 15-32°C (60-90°F)
- **Power supply:** 100-240V
- **Chassis:** Powder-coated steel
- **Nozzle diameter:** 0.4mm (0.015in)
- **Filament diameter:** 1.75mm (0.069in)
- **Layer resolution:** 100-340 micrometres (0.004-0.013in)

2005
The RepRap race
British academic Adrian Bowyer founds RepRap, an open-source initiative to build a 3D printer that can print most of its own components (right).

2008
Thingiverse
www.thingiverse.com launches as an open-source depositary in which people can upload and share CAD files for 3D models.

2009
Making history
MakerBot Industries starts shipping 3D printers, which focus on ease of use and low cost. 3,500 units have sold by 2011.



2011
Flying high
Engineers at the University of Southampton, UK, design and fly the world's first 3D-printed aircraft.

2012
New jaw
Doctors in Holland 3D print a prosthetic lower jaw for an 83-year-old woman. It is implanted successfully.

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WEIGHT 136g DIMENSIONS 130x65.6x9mm SCREEN RESOLUTION 1,280x768
PROCESSOR 1.5GHz (dual-core) RAM 2GB BATTERY 1,800mAh

DID YOU KNOW? The BlackBerry's manufacturer, Research In Motion (RIM), has recently rebranded to simply BlackBerry

Inside the BlackBerry Z10

How does BlackBerry's radically redesigned new smartphone work?

The Z10 is BlackBerry's new flagship smartphone, featuring a raft of improved hardware and a new operating system, BlackBerry 10.

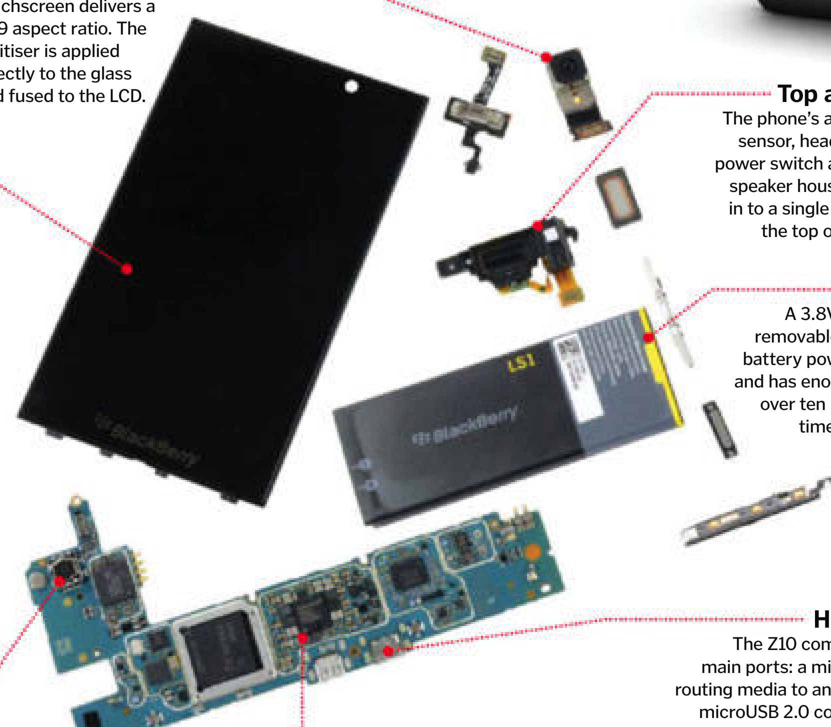
In terms of hardware, the Z10 is powered by a 1.5-gigahertz Qualcomm MSM8960 dual-core processor paired with two gigabytes of mobile DDR2 SDRAM, an internal bank of 16 gigabytes of flash memory and a large 3.8-volt lithium-ion battery. This core feature set is bolstered by the inclusion of an eight-megapixel rear-facing camera, a two-megapixel forward-facing camera and a 10.7-centimetre (4.2-inch), 1,280 x 768-pixel touchscreen – the latter coated with a layer of hardened, scratch-resistant glass.

The BlackBerry 10 OS is a proprietary variant based on QNX – a Unix-like embedded operating system – which allows for the integration of features such as multitouch gestures, advanced multitasking operations, screen-shared video calls and voice control of the device. Indeed, the 10 OS is heavily optimised for multitouch gestures and is based around a piece of software called BlackBerry Hub, a content and connectivity aggregator that displays a lot of key data in list form.

In terms of connectivity, the Z10 is installed with an NFC (near-field communication) antenna built in to the backplate and has support for both Wi-Fi and Bluetooth 4.0 connectivity. The Z10 is compatible – dependent on model – with network connections up to 4G LTE.

Z10 teardown

Learn what technology is packed into this new BlackBerry handset



Screen
The Z10's 10.7cm (4.2in), 356 ppi touchscreen delivers a 15:9 aspect ratio. The digitiser is applied directly to the glass and fused to the LCD.

Back camera
The Z10's rear-facing, 8MP auto-focus camera has a five-element f/2.2 lens, dedicated image signal processor and 64MB frame buffer.

Top assembly
The phone's ambient light sensor, headphone jack, power switch and earpiece speaker housing are built in to a single assembly at the top of the device.

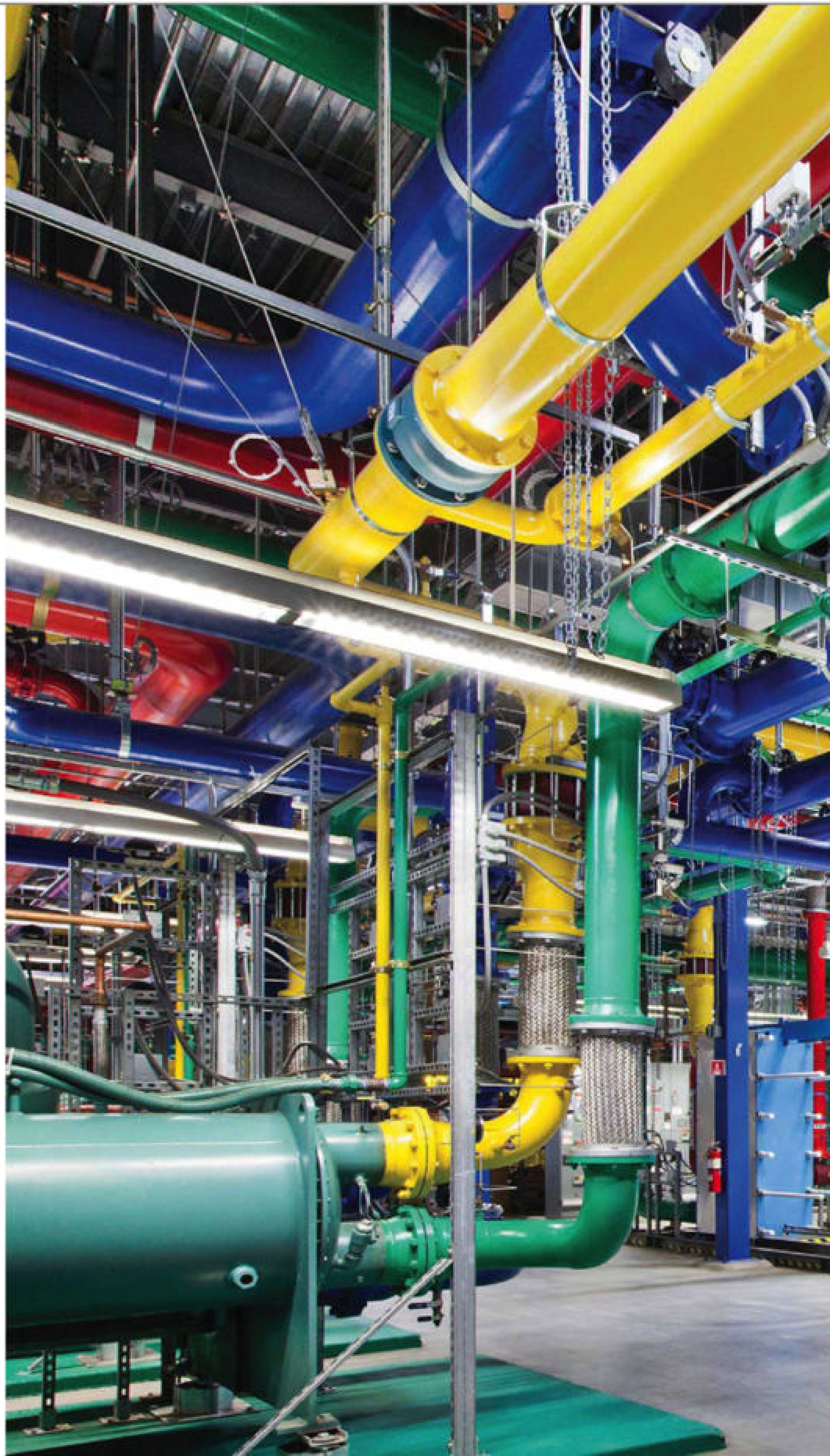
Battery
A 3.8V, 1,800mAh removable lithium-ion battery powers the Z10 and has enough juice for over ten hours of talk time per charge.

HDMI port
The Z10 comes with two main ports: a microHDMI for routing media to an HDTV and a microUSB 2.0 connection for charging and data transfer.

Front camera
A 2MP, fixed-focus camera is also included. This offers image and video stabilisation, a 3x digital zoom and 720p video recording.

Motherboard
The mainboard holds a bounty of chips and integrated circuits including 16GB of NAND flash memory, accelerometer and dual-core Snapdragon CPU.

"Data centres have grown in proportion with the expansion of the internet in the last 20 years"



Inside Google

What equipment does the internet giant use to link up the world?

To keep its search engine (as well as many other products) running around the clock, Google maintains 13 large data centres across the globe. Data centres themselves, as facilities that house computer systems, have existed for decades. They're commonly used to back up data in large archives or – as is more common with the onset of cloud computing – access to IT resources. Data centres have grown in proportion with the expansion of the internet in the last 20 years. Today they can take up the same space as an industrial plant, require tight security (both physical and logical) and contain millions of pounds worth of computing equipment.

Currently six of Google's data centres are located in the US, one in South America, three in Europe and three in Asia. They prioritise efficiency by focusing on the way power is distributed and cooling, with environmental impact in mind. The servers are a proprietary and patented modular format housed in their hundreds in individual shipping containers. But rather than using a huge, centralised uninterruptible power supply (UPS) for each facility, Google includes a battery on each server which is much more power efficient.

Data centres can run very hot if left unchecked – especially in summer. To combat this some are strategically located, like the Hamina facility in Finland, which uses the icy waters of the fjords to keep machinery cool.

THE STATS
GOOGLE IT

DATA CENTRES WORLDWIDE 13

FACILITY BUILD COST £400m

SERVERS PER CONTAINER 1,000+

CONTAINERS PER FACILITY 45+

DATA CENTRE POWER USAGE 103MW

SERVER BATTERY EFFICIENCY 99.9%

DID YOU KNOW? *Google's entire server network in 1998 could be replicated thousands of times by a single container today*

"Thanks to multiple processing units, the EXPEED 3 image engine can perform several tasks in parallel"

Inside a full-frame DSLR

The tech in the Nikon D600 that allows for wide-angle photography

The D600 is a new DSLR camera from Nikon that is designed to deliver the performance of a full-frame professional model but at a lower price point.

The full-frame capability – see the 'What does "full frame" mean?' boxout for more information – comes courtesy of a 35.9 x 24-millimetre (1.4 x 0.9-inch) complementary metal-oxide semiconductor (CMOS) sensor capable of generating images up to 24.3 megapixels. This contrasts to other models in its price range that tend to feature cropped, half or quarter-frame sensors. This is due to the traditionally high cost of full-frame sensors, which generally has resulted in fewer being manufactured per silicon wafer.

Images captured by the full-frame sensor are processed by an EXPEED 3 image engine. This is a multi-CPU media processor that can handle a range of tasks such as colour reproduction, gradation processing, image sharpening, gamma correction and compression. Thanks to the multiple processing units, the EXPEED 3 image engine is capable of performing several tasks in parallel, enabling the camera to shoot at up to 5.5 frames per second (fps).

Arguably the D600's most important feature though – compared with other high-end full-frame cameras – is its compact design (14.2 x 11.2 x 8.1 centimetres/5.6 x 4.4 x 3.2 inches) and low weight; eg the D600 weighs in close to 200 grams (seven ounces) lighter than the Canon 5D Mark III. This has been achieved in a number of ways including integrating dual SD card slots instead of a CompactFlash (CF) port, as well as smaller internal chipsets and boards.

D600 teardown

We break open Nikon's D600 to examine its advanced components

CMOS sensor
The D600 boasts a full-frame 35.9 x 24mm (1.4 x 0.9in) sensor with 24.7mn total pixels. It can deliver a maximum image resolution of 6,016 x 4,016px.

Power board
One of two boards that control the distribution of electrical power between the camera's components.

LCD segment driver
The LCD segment driver reduces load on the D600's processing units, handling all screen operations.

Battery
A 7V, 1,900mAh lithium-ion cell provides about 900 shots per charge.

The statistics...

Nikon D600

Type: DSLR
Weight (body only): 760g (26.8oz)
Sensor type: CMOS
Effective pixels: 24.3mn
Maximum image size: 6,016 x 4,016px
Shutter speed range: 1/4,000 to 30 seconds
Max shooting speed: 5.5 fps
ISO range: 100–6,400

HEAD2HEAD

D600 RIVALS

1. ENTRY DSLR

Nikon D7100

This entry-level DSLR also from Nikon is roughly half the cost of the D600, but only packs a 23.5 x 15.6-millimetre (0.9 x 0.6-inch) CMOS sensor.

2. DIRECT RIVAL

Canon EOS 6D

Costing slightly less than the Nikon D600, the 6D from Canon offers a comparable full-frame sensor, but has a cap of 20.2 megapixels.

3. SPEEDY AF

Olympus OM-D E-M5

An interchangeable-lens mirrorless camera, the E-M5 has a far smaller sensor, but a super-quick autofocus function.

DID YOU KNOW? *The term DSLR is short for 'digital single-lens reflex' camera*

SD card slots

Twin SD card slots are situated on the right-hand side. The use of SD over CF cards makes the camera both smaller and lighter.

Flash capacitor

This supplies the high current to operate the camera's high-voltage flash tube.

LCD

The 8.1cm (3.2in), 921,600-dot LCD screen is fused to the rear casing.

Tripod mount

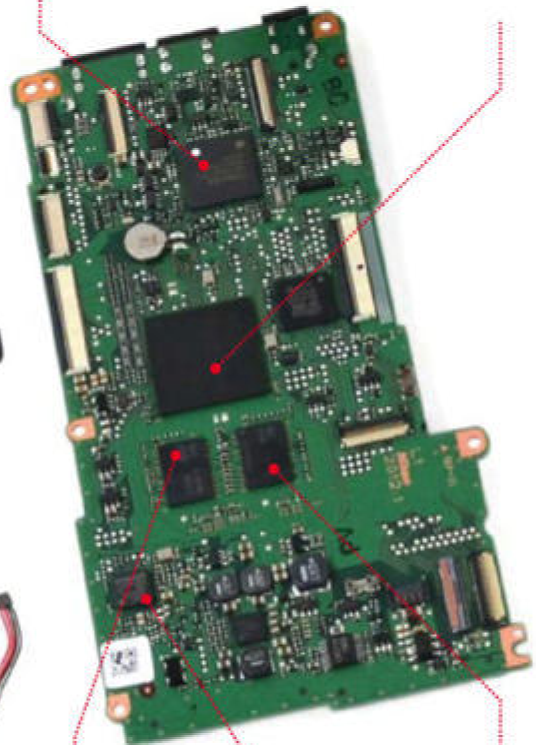
A standard screw fitting for a tripod is fixed to the bottom of the casing.

Lens mount

A metal lens mount allows for a wide variety of lenses to be fitted to the D600.

Mainboard up close

The D600's mainboard carries a selection of essential chips…



Microcontroller

An 80MHz low-power microcontroller that has built-in NANO FLASH for speedy computations.

EXPEED 3 image-processing engine

The most important chip on the mainboard, this is a comprehensive multi-core processor that handles almost all image adjustments.

SDRAM

1GB of DDR3 SDRAM acts as a conduit between the board's selection of chips.

Flash memory

A small bank (16MB) of flash memory allows for very fast random access to data.

SD card controller

This chip provides ultra-high-speed SD card read and write operational support.

What does 'full frame' mean?

A 'full-frame' DSLR is a camera that is installed with an image sensor that is the same size as a 35-millimetre (1.4-inch) film frame. The key benefit of this is that images shot onto full-frame sensors are not cropped as they are on smaller sensors, granting a larger angle of view. For example, a 24-millimetre (0.9-inch) lens on a full-frame sensor DSLR delivers an 84-degree viewing angle, while on a sensor with a 1.5 crop factor, that angle drops to only 62 degrees. In addition, full-frame sensors allow for larger photosites (that is, individual light-sensitive spots), which makes for a wider dynamic range (spectrum of light/shadow) and lower noise, so images stay crisp even when blown up.

TOXIC SCIENCE

Discover some of the deadliest substances known to humankind

Toxic substances include anything that can physically harm us after we inhale, swallow or touch it, from an innocent bee sting to full-blown cyanide poisoning. Defining toxicity is tricky since almost anything is poisonous at high enough doses – even water. Acute poisoning follows just one exposure, for example, nibbling a death cap mushroom, but chronic exposure – like inhaling cigarette smoke over decades – can be equally, if not more, damaging.

Toxins are toxic substances produced by living organisms. They use toxins mainly to ward off predators or paralyse prey. Small but deadly bacteria produce some of the most potent toxins known, including botulinum toxin A (Botox). Other toxic substances occur naturally on Earth, such as the hydrogen sulphide produced by volcanic eruptions. We humans have even invented man-made ones for use as pesticides, insecticides (eg DDT) or chemical weapons (eg sarin, VX).

Targeting different parts of the body, toxic substances can damage us in an alarming number of ways. Neurotoxins are some of the most effective, affecting the brain and nervous system and causing muscles to freeze or twitch uncontrollably. Other substances can burst our red blood cells or cause allergic reactions.

But not everyone is affected by toxic substances in the same way. How toxic a chemical is depends on how easily it is absorbed, metabolised and eventually expelled by the body. Children are generally more vulnerable as their bodies are not able to get rid of toxic substances as effectively. Different species are also more or less susceptible to various poisons – for example, it takes 1,000 times more dioxin to kill a hamster than a guinea pig.

Key

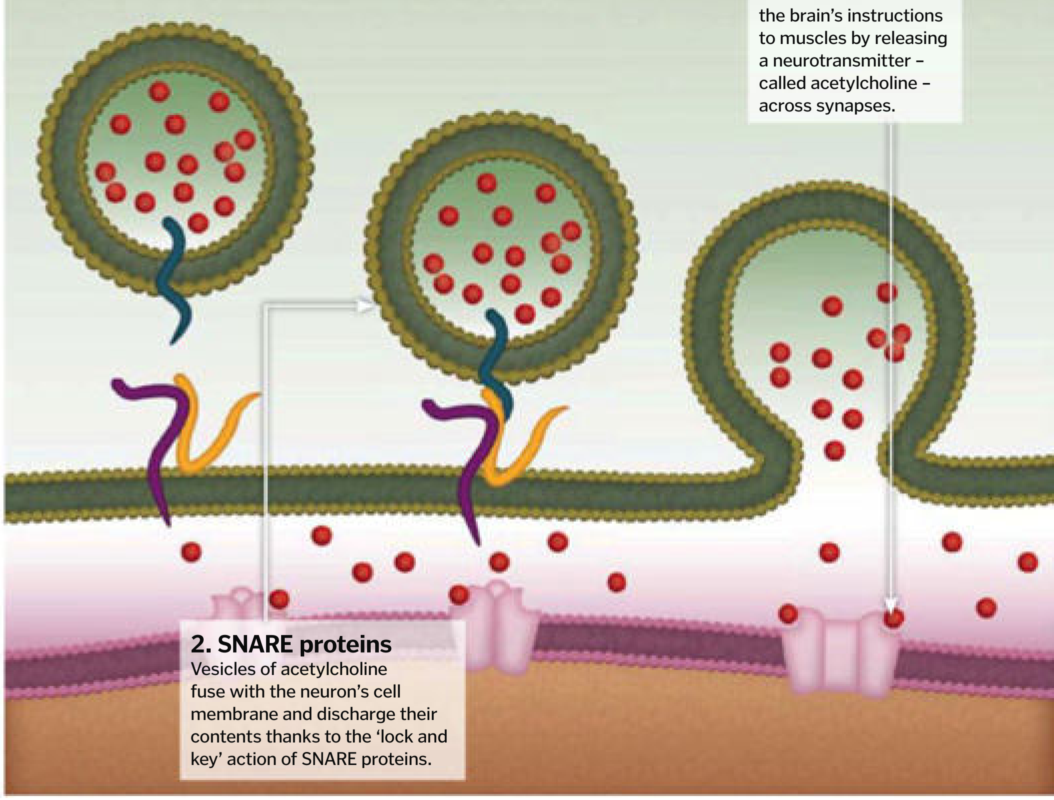
Toxicity: 1 – Unlikely to kill / 5 – Super-deadly
Rarity: 1 – Very common / 5 – Very rare

Botulinum toxin A (Botox)

This is the most toxic substance in nature: just one gram (0.04 ounces) could kill 14,000 people if swallowed – or 8.3 million if injected! Produced by Clostridium botulinum bacteria, this neurotoxin is responsible for botulism, a rare but life-threatening illness transmitted principally through contaminated canned food. Botulinum disrupts communication between nerves and muscle cells, gradually paralysing its victims and finally leading to respiratory failure. Extremely small doses of botulinum toxin can, however, be used to treat muscle spasms and excessive sweating and to paralyse the muscles that cause wrinkles (sold commercially as Botox).

The statistics…

Main symptoms: Double vision, droopy eyelids, difficulty swallowing, slurred speech, muscle weakness, paralysis
Antidote: Horse-derived antitoxin
Time to death: Rarely fatal when treated
Toxicity rating: 5
Rarity rating: 4



1. Synapse
Neurons communicate the brain's instructions to muscles by releasing a neurotransmitter – called acetylcholine – across synapses.

2. SNARE proteins
Vesicles of acetylcholine fuse with the neuron's cell membrane and discharge their contents thanks to the 'lock and key' action of SNARE proteins.

5 TOP FACTS
TOXIC PLANTS

Castor oil plant
1 Listed by the *Guinness Book Of World Records* as the most poisonous plant on Earth, the ricin contained in one castor bean can easily finish off the average human.

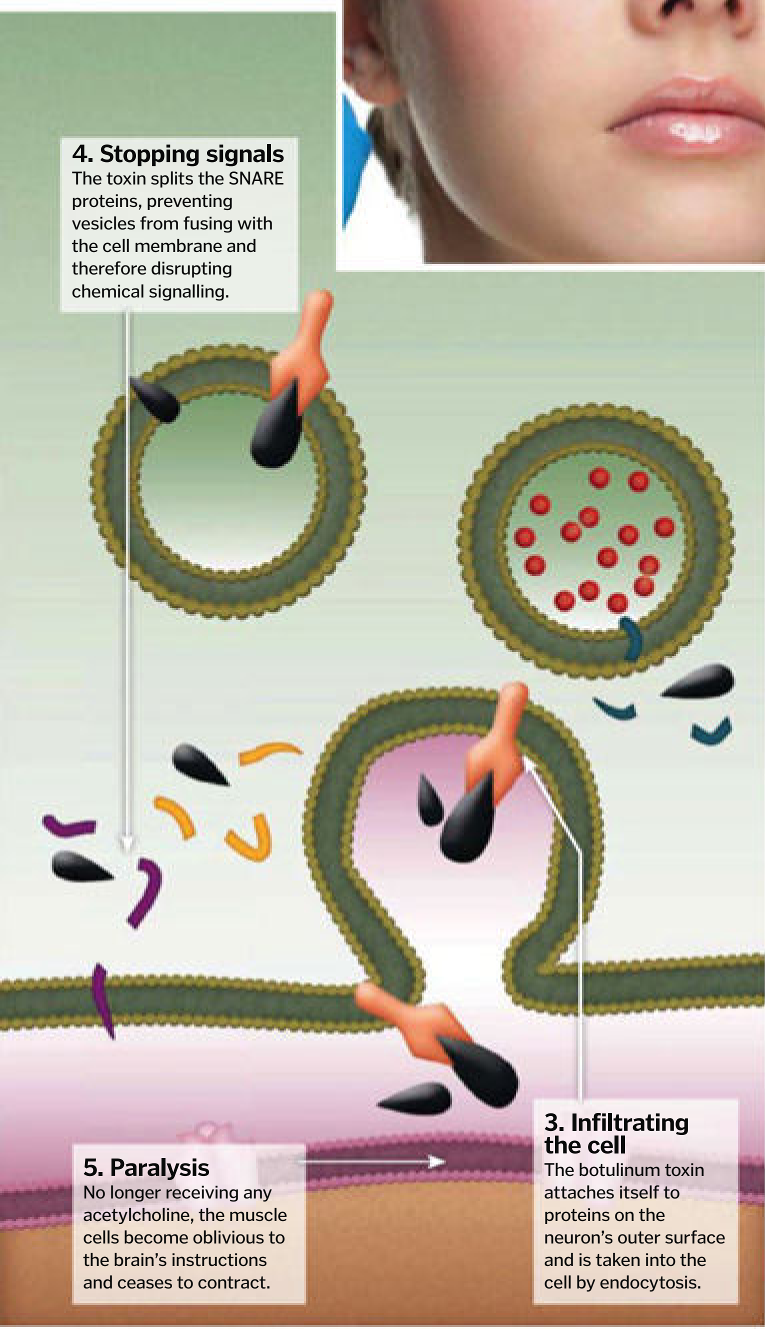
Oleander
2 Don't let its pretty blooms fool you – oleander contains potent glycosides which target the heart, provoking heart attacks in those who eat its flowers, leaves or fruit.

Rosary pea
3 The colourful seeds of Abrus precatorius are sometimes used to make jewellery, but they can poison handlers with abrin, a toxin which attacks protein-building ribosomes.

Belladonna
4 Also called deadly nightshade, this attractive plant contains a mix of alkaloids and was a popular poison in Ancient Roman times. Just one leaf is enough to kill a person.

Water hemlock
5 Native to North America, this plant contains cicutoxin, a neurotoxin which causes seizures, violent muscle contractions and loss of consciousness if ingested.

DID YOU KNOW? *Exposure to mercury in felt caused dementia in many 18th-century milliners – hence 'mad as a hatter'*



Asbestos

Asbestos is the name given to a handful of different minerals which share one common feature: bunches of fibrous crystals. Boasting an array of insulating properties topped off with a low price tag, asbestos was a popular building material until its toxic effects came to light. With repeated inhalation, asbestos fibres accumulate in the lungs, causing deadly diseases like asbestosis, an inflammatory lung condition, and cancer. These diseases typically don't develop until 15-30 years after exposure. Although now banned in most countries, older buildings can still release the harmful crystals when demolished.

The statistics...

Main symptoms: Shortness of breath, coughing, chest pain
Antidote: No current cure for asbestosis, but relief treatment
Time to death: Various
Toxicity rating: 4
Rarity rating: 3

Ricin

Found in the castor oil plant, ricin is a toxic protein that wreaks havoc on ribosomes, the cell's protein builders. The result is severe damage to major organs. Just one milligram of ricin is enough to kill an adult if inhaled or ingested, leading many countries to investigate its use as a biological weapon. The castor oil plant's popularity as an ornamental shrub and the relative ease of extracting the toxin from castor beans have also made ricin the poison of choice for many assassins.

The statistics...

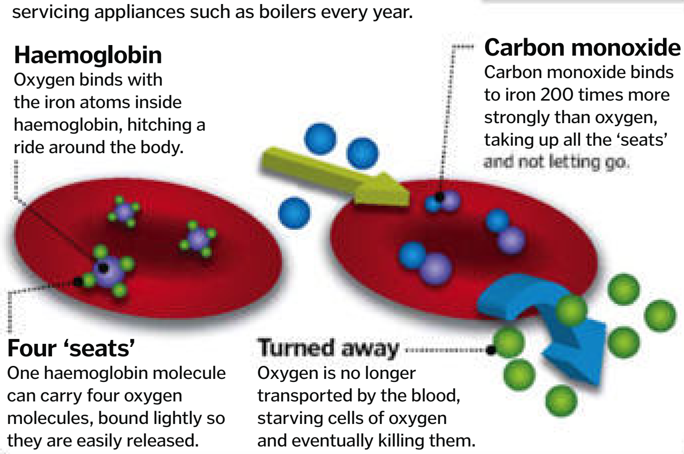
Main symptoms: Diarrhoea, nausea, accelerated heart beat, hypotension, seizures
Antidote: The UK military has developed an antidote, but it remains to be tested on humans
Time to death: 2–5 days
Toxicity rating: 5
Rarity rating: 2

Carbon monoxide

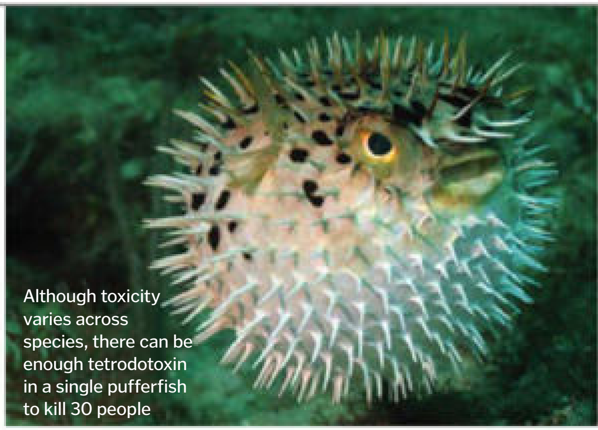
Colourless and odourless, carbon monoxide gas has a knack for going unnoticed. It is produced by the incomplete combustion of organic fuels including gas, coal and wood – occurring, for example, when inadequate ventilation deprives a gas-burning stove of oxygen. As a result, carbon monoxide poisoning is the most common type of air poisoning around the home. Carbon monoxide molecules bind tightly to haemoglobin, the oxygen-carrying protein in blood. Taking oxygen's place, they prevent blood from delivering oxygen to cells. You can reduce the risk by keeping your home well ventilated and servicing appliances such as boilers every year.

The statistics...

Main symptoms: Headache, nausea, vomiting, dizziness, fatigue, weakness, loss of consciousness
Antidote: Oxygen
Time to death: 2-3 minutes in acute cases
Toxicity rating: 4
Rarity rating: 1



> "Although chefs need a licence to serve fugu, mishaps still poison an estimated 200 people each year"



Although toxicity varies across species, there can be enough tetrodotoxin in a single pufferfish to kill 30 people

Tetrodotoxin

Thrill-seeking Japanese diners are sometimes tempted to try fugu, a variety of pufferfish. The catch? If the chef slips up, they risk being poisoned with tetrodotoxin, a potent neurotoxin contained in the fish's gonads, liver, intestines and skin. Opening nerves' ion channels, tetrodotoxin acts similarly to batrachotoxin to block nerve impulses, causing paralysis and death by respiratory failure. Although chefs need a licence to serve fugu, mishaps still poison an estimated 200 people each year, with half of them dying. Pufferfish are not the only ones to use tetrodotoxin; it is one of the most common toxins in the marine world, employed by scores of fish, crabs and molluscs, including the blue-ringed octopus.

The statistics…

Main symptoms: Numbness of the lips and tongue, followed by paralysis that spreads to the entire body, heart failure

Antidote: None known

Time to death: 4-6 hours

Toxicity rating: 4

Rarity rating: 4

Toxic household

Keep an eye on the toxic substances lurking in your home…

Phthalates
Personal care products, and also vinyl flooring, can contain phthalates – substances linked to changes in hormone levels and liver cancer.

Medicines
The medicine cabinet is the greatest source of accidental poisonings in the home, with most drugs harmful when taken in excessive doses.

Bisphenol A
BPA, a chemical found in plastic bottles, mimics the hormone oestrogen, possibly causing reproductive damage.

Household cleaners
Ingredients such as ammonia or bleach cause skin or lung irritation. Mixing different cleaners can also produce dangerous acids.

Cyanide

Whether inhaled or ingested, cyanide is one of the fastest-acting poisons known, sealing death sentences in minutes. Chemically speaking, a cyanide is a compound with a triple bond between a carbon and a nitrogen atom. Hydrogen cyanide gas and solid sodium or potassium cyanide are highly toxic, preventing the body's cells from using oxygen and starving the heart and the brain. Certain fruit pits contain cyanide and small quantities of hydrogen cyanide are present in engine exhaust fumes. Industrial uses include gold mining and pesticides – one of which was used by the Nazis in gas chambers.

The statistics…

Main symptoms: Nausea, rapid breathing, dizziness, headache, convulsions – leading to death

Antidote: In smaller doses hydroxocobalamin is one known antidote, but generally fatal

Time to death: As little as a minute

Toxicity rating: 5

Rarity rating: 2

Sarin

Sarin is a man-made nerve agent, first developed as a pesticide by German scientists in 1938. A colourless, tasteless but extremely volatile gas, it works by inhibiting the body's enzyme which breaks down the neurotransmitter acetylcholine, causing it to accumulate at nerve endings. This signals to muscles to contract uncontrollably, triggering a range of unpleasant effects which culminate in death by asphyxiation. Like all chemical weapons, sarin is outlawed and has been used only a handful of times: like during the Iran-Iraq War in the Eighties, and in terrorist attacks on the Tokyo subway in 1995.

The statistics…

Main symptoms: Constriction of pupils, drooling, difficulty breathing, loss of control over bodily functions, convulsions

Antidote: Atropine

Time to death: 15 minutes to a few hours

Toxicity rating: 5

Rarity rating: 5

1. DEADLY

Taipan
Found in inland Australia, Earth's most venomous snake paralyses its victims with a powerful neurotoxin, usually killing in under 45 minutes.

2. DEADLIER

Golden poison-dart frog
The most poisonous of its family, this 2.5-centimetre (one-inch)-long amphibian has enough batrachotoxin to take out nine people!

3. DEADLIEST

Box jellyfish
This jellyfish's tentacles deliver a deadly blend of toxins simultaneously targeting the heart, nervous system, skin and red blood cells.

DID YOU KNOW? *Caffeine can be deadly – but only if you were to down about 90 cups of coffee in quick succession!*

Flame retardants
PBDEs (polybrominated diphenyl ethers) found in mattresses and furniture to make them fireproof may cause learning and memory deficits.

VOCs
Just after fitting, the glues and dyes used in new flooring can emit harmful volatile organic compounds (VOCs).

Carbon monoxide
Gas-burning fires can produce potentially deadly carbon monoxide gas if they don't receive enough ventilation.

Lead paint
Houses built before 1978 may contain neurotoxic lead-based paint which can be exposed if it peels.

Cigarettes
Smokers inhale over 700 poisons with each drag, including arsenic, benzene, cadmium, hydrogen cyanide, carbon monoxide and even radioactive polonium-210.

Garden chemicals
Exposure to pesticides, herbicides and fertilisers has been linked to asthma as well as various neurological, developmental and immunological disorders.

TCDD

TCDD is the deadliest of the dioxins. These chemicals occur in the natural world but are produced in much larger quantities by industry. Dioxins persist for a long time, accumulating in the fat cells of living organisms. As a result, small quantities of dioxins may go unnoticed, but over time they can damage the immune and reproductive systems and increase the likelihood of diabetes and cancer. High doses such as those experienced during the Vietnam War with the USA's use of Agent Orange – a herbicide contaminated with TCDD – spark an immediate reaction. They are also thought to cause cancer and birth defects years later, although TCDD's effect on the body is not yet fully understood.

The statistics...

Main symptoms: Skin disease (chloracne) and discolouration, lung infection; in the longer term: cancer, birth defects

Antidote: None

Time to death: Unconfirmed

Toxicity rating: 4

Rarity rating: 2

Batrachotoxin

Batrachotoxin is the deadliest ingredient in a lethal cocktail of toxins secreted by certain poison-dart frogs. Native tribes use it as a weapon, dipping their blowgun dart tips in the frogs' toxins – these darts kill prey almost instantaneously. The frogs don't actually produce batrachotoxin themselves but obtain it by eating poisonous beetles. Batrachotoxin opens nerve cells' ion channels permanently, preventing them from creating an electric potential. This blocks cell signalling, paralysing muscles. Heart muscles are particularly sensitive to the toxin, leading to an irregular pulse and, soon after, a heart attack.

The statistics...

Main symptoms: Convulsions, salivation, muscle contractions

Antidote: None

Time to death: Under 10 minutes

Toxicity rating: 5

Rarity rating: 4

Worst of the rest

1 Alpha-amanitin
This deadly toxin is taken up by the liver, where it inhibits an enzyme needed for cell division, causing liver failure.
Found in: Death cap and destroying angel mushrooms

2 Arsenic
Once believed to have killed Napoleon (now disproved), arsenic disrupts cells' energy transport, leading to organ failure.
Found in: Wood-preserving chemicals, insecticides

3 VX
VX is the most toxic nerve agent ever synthesised – ten times more toxic than sarin.
Found in: Russia and the USA – but now being destroyed

4 Strychnine
This poison causes some gruesome symptoms such as muscle convulsions, arching of the body and facial spasms.
Found in: Strychnos trees, rodent pesticides

5 Polonium-210
If ingested, this radioactive material bombards the body with deadly alpha particles.
Found in: Certain rocks, can settle on broad-leaf plants

Digitalis

Digitalis, or foxglove, owes its toxicity to cardiac the glycosides digitoxin and digoxin – compounds with the capacity to both help and harm. When ingested, glycosides affect the behaviour of heart muscles. In controlled doses, they can regulate the heart beat and treat congestive heart failure. But taking too much digitalis medication, or eating parts of the plant, can trigger a fatal heart attack; that said, eating foxgloves usually induces vomiting which prevents overdose. US serial killer Charles Cullen poisoned at least 29 elderly patients in nursing homes by administering overdoses of insulin and digoxin.

The statistics...

Main symptoms: Nausea, vomiting, diarrhoea, visual disturbances, hallucinations, reduced heart rate

Antidote: Digoxin Immune Fab: this binds to the toxin, preventing it from acting on the body

Time to death: Rarely fatal but can kill in 24 hours

Toxicity rating: 3

Rarity rating: 2

"On Earth, lightning is our most famous naturally occurring plasma, along with the spectacular auroras at the poles"

Understanding plasma

We look beyond solids, liquids and gases and put the fourth state centre stage

The tip of a welder's torch glows like the Sun and fires out a concentrated blast of heat in excess of 3,000 degrees Celsius (5,430 degrees Fahrenheit). Its UV rays are so harmful that welders wear dark face plates to protect them from 'arc eye', a painful burning of the cornea. The source of the intense glow is an ionised arc of gas called plasma.

Plasma is the fourth state of matter – along with solid, liquid and gas – and it's the most abundant form of matter in the observable universe. The Sun is a massive ball of plasma, as is every star and every inch of space between planets and solar systems. On Earth, lightning is our most famous naturally occurring plasma, along with the spectacular auroras at the poles.

Given its abundance, it's quite surprising plasma wasn't identified until the Twenties. That's because electrons weren't discovered until the late-19th century, and without an understanding of subatomic charged particles, you can't understand how plasma works.

Plasma is formed by superheating a gas. Normally, atoms in a gas move freely, but their electrons are still bound to their nuclei. With enough energy though, electrons pull free of their nuclei, leaving behind positively charged ions. This ionised state is a highly efficient conductor and is the birthplace of plasma.

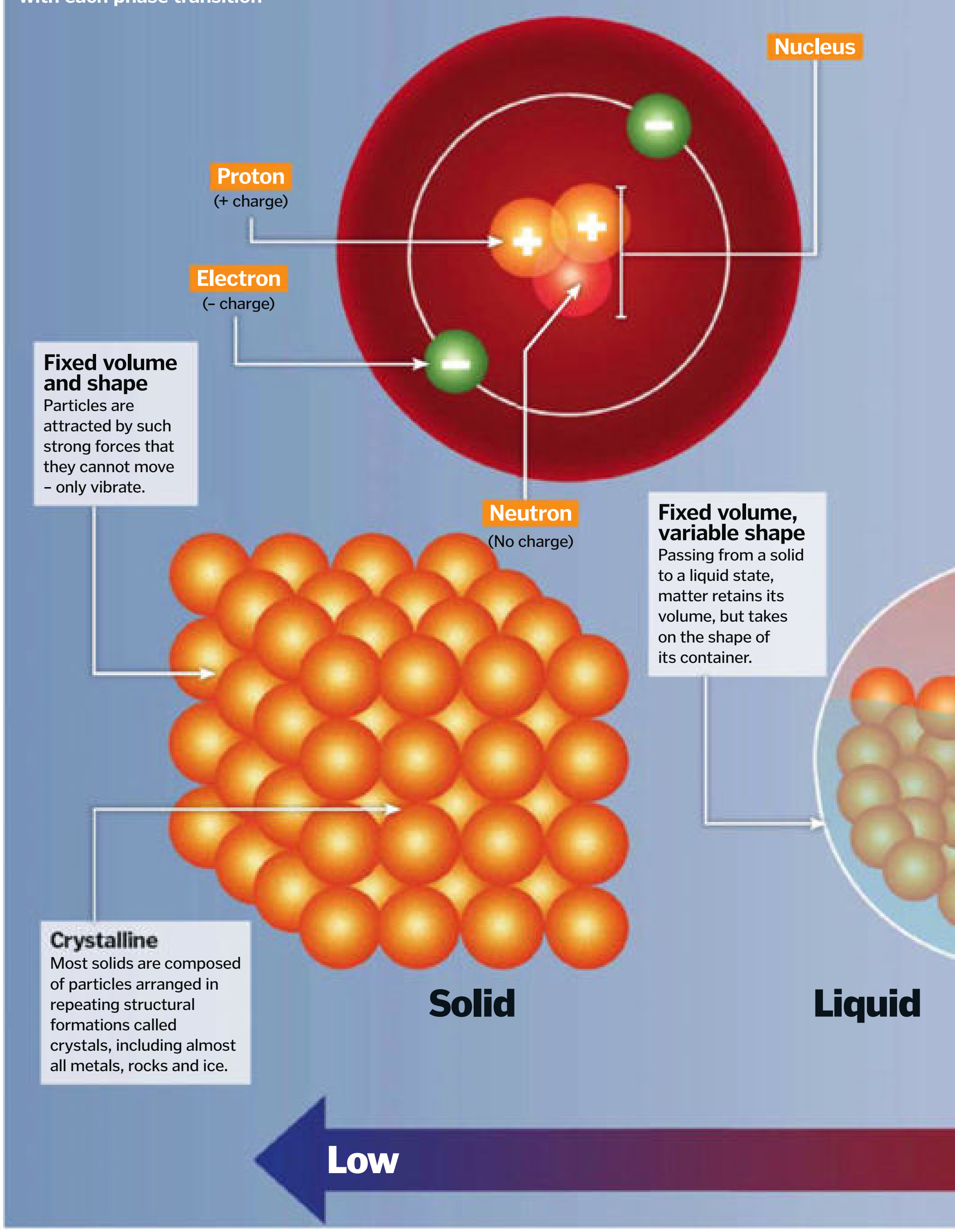
The glowing tip of a welder's torch is really a plasma arc. The torch is attached to a tank of inert gas like argon or helium. Inside the tip of the torch is a tungsten electrode with an opposite charge as the piece of metal being welded. When a high-voltage current is passed through the tungsten electrode, it ionises atoms in the gas stream, converting that current into a white-hot jet of plasma.

The role of ionisation

In a normal state, atoms are electrically neutral, meaning there are an equal number of positively charged protons and negatively charged electrons (neutrons, by definition, are neutral). Ionisation occurs when that balance is tipped by the loss or gain of electrons. If an electron absorbs enough energy, it will escape from its atomic orbit, leaving behind a positively charged ion. Sometimes these free electrons have sufficient energy to enter another atom's orbit, which is how negatively charged ions form.

Getting in a state

The properties and qualities of matter change significantly with each phase transition



STRANGE BUT TRUE
PLASMA APLENTY

How much of the known universe is plasma?

A 9.9% B 60% C 99%

Answer:
99 per cent of the matter we can touch, see or detect with telescopes is plasma. That's largely because the universe's most massive bodies – stars – are almost entirely plasma. Beyond this, 90 per cent of the universe is unobservable dark matter.

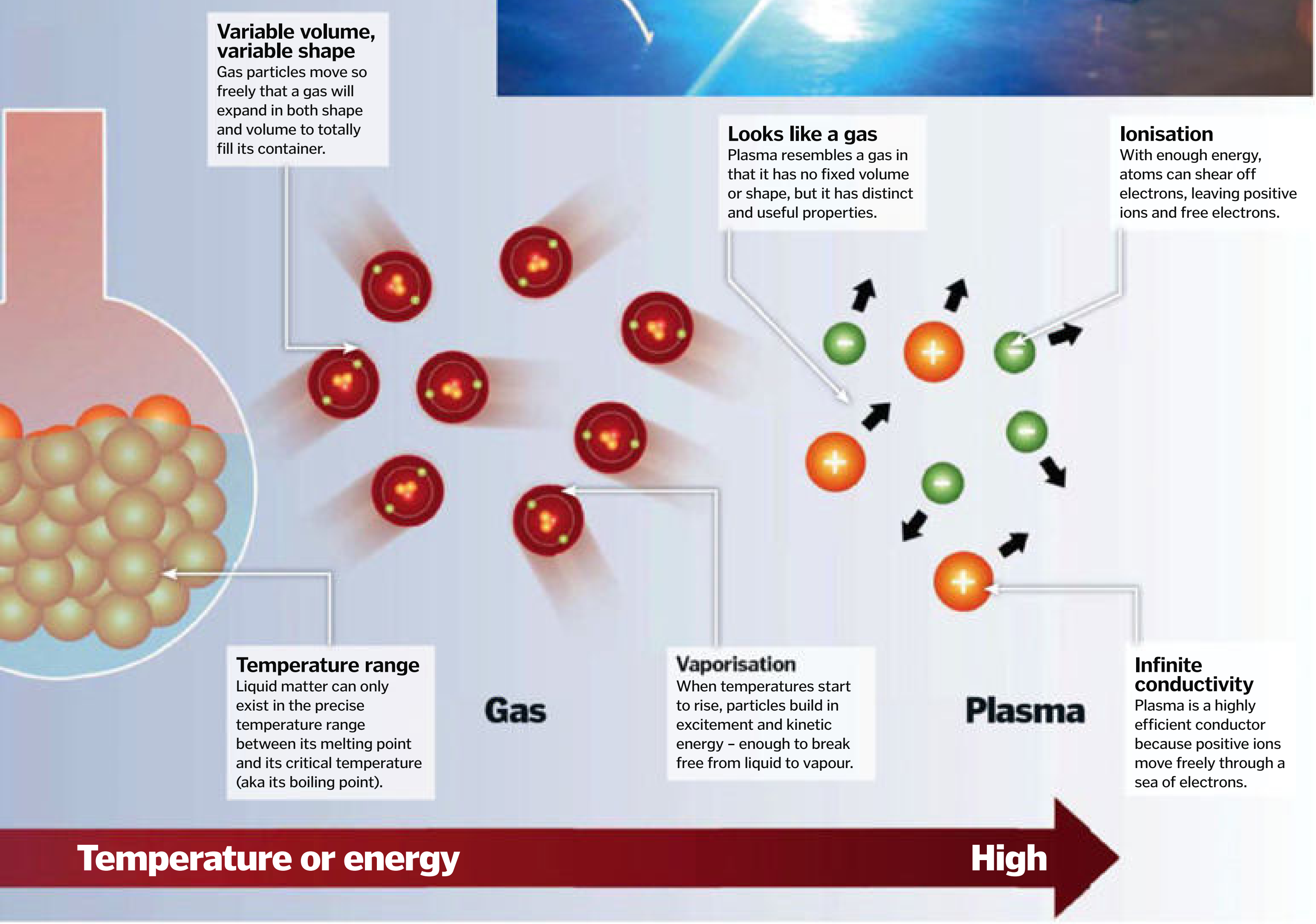
DID YOU KNOW? *American physicist Irving Langmuir gave plasma its name in 1927 because it reminded him of blood plasma*

Can water ever turn into plasma?

Water is the only substance on Earth that occurs naturally as a solid, liquid and gas. With water, each state of matter is accompanied by a related phase transition. Liquid water freezes to become a solid and boils to become a vapour. But is there any phase transition that could ever turn water into a plasma? Not exactly. Whether as ice, liquid water or water vapour, water retains the same molecular structure: H_2O.

For water to become a plasma, the individual hydrogen and oxygen atoms would need to be broken apart and ionised separately. And if the molecular structure is broken apart, then water is no longer water. An elemental gas like hydrogen can transition between gas and plasma and back to gas. But once water molecules are split apart and ionised, those disparate atoms will not naturally return back to a water form.

The welder's torch converts a high-voltage electrical current into a white-hot plasma arc



> "The anaesthetic medication causes a warm feeling and numbness leading to the area being fully anaesthetised"

How epidurals work

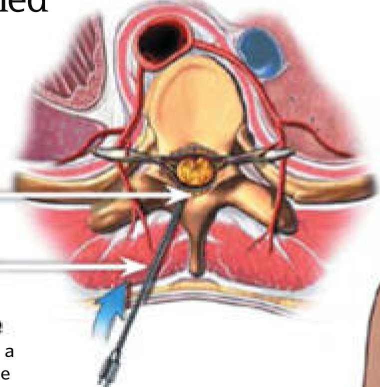
The science behind blocking pain explained

An epidural (meaning 'above the dura') is a form of local anaesthetic used to completely block pain while a patient remains conscious. It involves the careful insertion of a fine, long needle deep into an area of the spine between two vertebrae of the lower back.

This cavity is called the epidural space. Anaesthetic medication is injected into this cavity to relieve pain or numb an area of the body by reducing sensation and blocking the nerve roots that transmit signals to the brain.

The resulting anaesthetic medication causes a warm feeling and numbness leading to the area being fully anaesthetised after about 20 minutes. Depending on the length of the procedure, a top-up may be required.

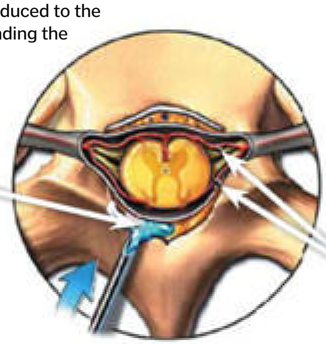
This form of pain relief has been used widely for many years, particularly post-surgery and during childbirth.

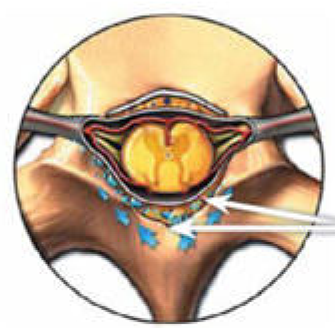


1. Epidural space
The outer part of the spinal canal, this cavity is typically about 7mm (0.8in) wide in adults.

2. Epidural needle
After sterilising the area, a needle is inserted into the interspinous ligament until there is no more resistance to the injection of air or saline solution.

3. Anaesthetic
Through a fine catheter in the needle, anaesthetic is carefully introduced to the space surrounding the spinal dura.

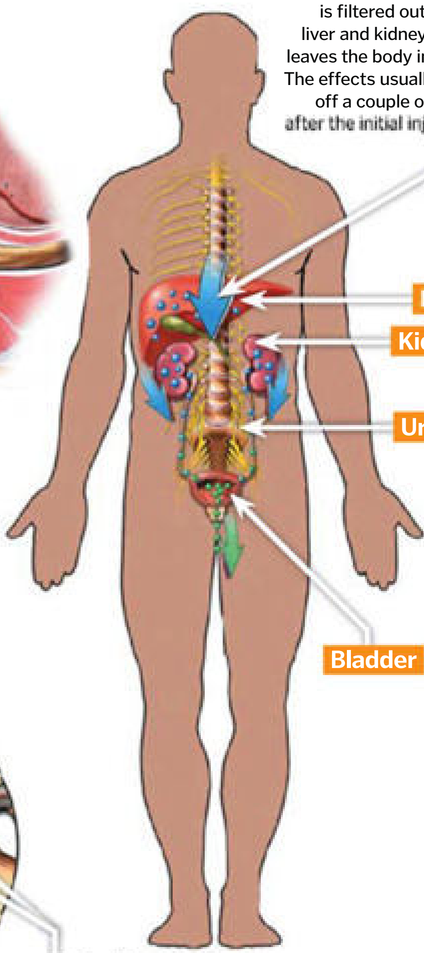




4. Absorption
Over about 20 minutes the anaesthetic medication is broken down and absorbed into the local fatty tissues.

5. Radicular arteries
The anterior and posterior radicular arteries run with the ventral and dorsal nerve roots, respectively, which are blocked by the drug.

6. Processing
Anaesthetic in the blood is filtered out by the liver and kidneys, then leaves the body in urine. The effects usually wear off a couple of hours after the initial injection.



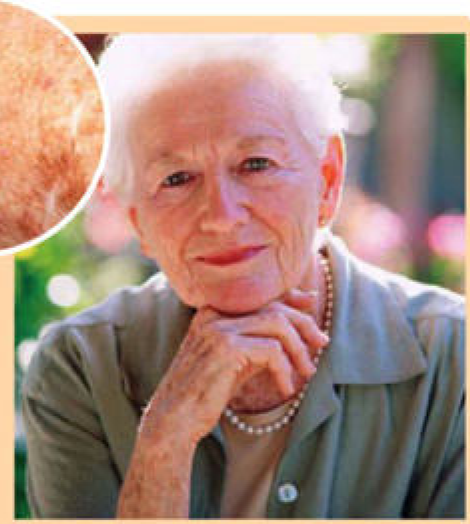
What are age spots?

Find out why these lesions appear as we grow old

Also known as solar lentigines, age spots are the oval-shaped lesions that appear on the skin over time. While age spots are caused by the damaging effects of the Sun, the marks themselves are not dangerous. It's Sun exposure rather than old age that causes them, and because they're linked to solar damage, they usually appear on exposed parts of the body like the backs of the hands and the tops of bald heads.

Normal skin gets its colour from the light-absorbing pigment melanin, which is produced by specialised cells called melanocytes deep in the skin. Sunlight hitting the skin activates and accelerates the production of melanin, which is drawn to the surface where it forms a dark barrier (tan) to protect the deeper layers of the dermis from harmful ultraviolet (UV) rays.

However, as our skin ages and becomes thinner and less elastic, pigments can accumulate in small pools near the surface causing these common blemishes.



2.72m

TALLEST MAN IN HISTORY

At 2.72 metres (eight foot, 11.1 inches) Robert Wadlow is the tallest man on record. A sufferer of gigantism, he was 0.9 metres (three feet) taller than his father. Sadly, he was only 22 when he died in 1940.

DID YOU KNOW? *In fish, the intermediate lobe controls skin colour change, while birds have no intermediate lobe at all*

Pituitary gland up close

What does this hormone factory do and why couldn't we live without it?

The pea-sized pituitary gland is found at the base of the brain, close to the hypothalamus. At a glance, it looks a relatively insignificant part of the brain, but it actually plays a role in many vital systems.

Often referred to as the 'master gland', it not only releases hormones that control various functions, but it also prompts the activity of other glands like the ovaries and testes.

The pituitary gland comprises three sections called lobes: the anterior, the posterior and the intermediate – the latter of which is considered part of the anterior lobe in humans. These work together with the hypothalamus, which monitors hormones in the blood and stimulates the pituitary gland to produce/release the appropriate hormone(s) if levels fall too low.

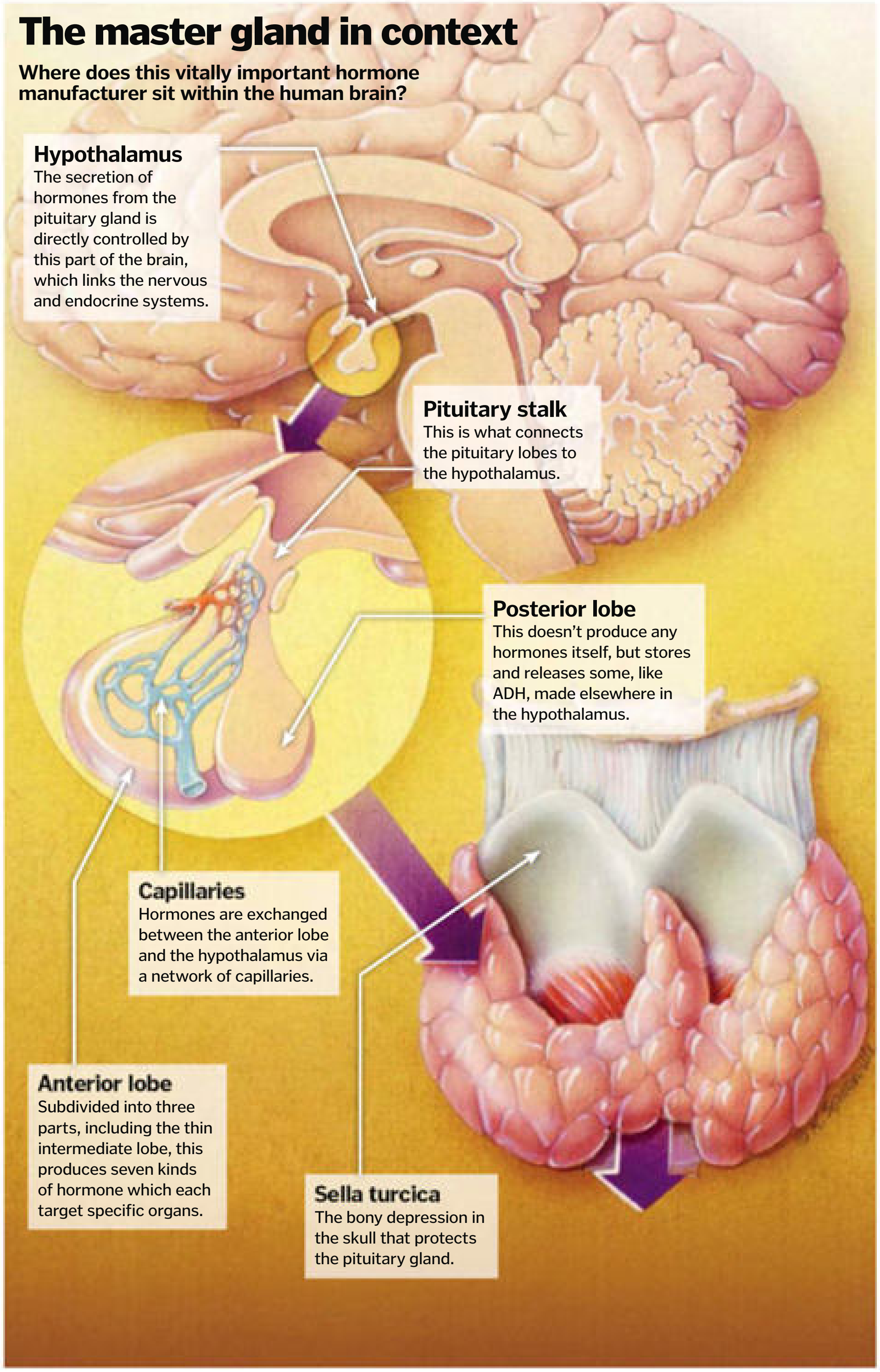
The anterior lobe produces seven important hormones, which include those that regulate growth and reproduction. Adrenocorticotropic hormone (ACTH) targets the adrenal glands to produce cortisol and controls metabolism, while luteinising hormone triggers ovulation in women and stimulates testosterone production in men. The posterior lobe, meanwhile, doesn't *generate* any hormones itself, but stores two: antidiuretic hormone (ADH), which decreases urine production by making the kidneys return more water to the blood, and oxytocin, which tells the uterus to contract during childbirth and also prompts milk production.

Gigantism in focus

The pituitary gland also produces growth hormone, which in adults controls the amount of muscle and fat in the body and plays a key role in the immune system. In children, of course, growth hormone has a very noticeable effect in increasing height and bulk until adulthood. However, sometimes the pituitary gland becomes hyperactive – often as a result of a benign tumour – and produces excess growth hormone. In these cases, a person can grow to a far-beyond-average height, with hands, feet and facial features growing proportionally. While this might not seem so bad, gigantism is nearly always accompanied by other health issues, such as skeletal problems, severe headaches and more life-threatening conditions like heart disorders. If diagnosed early, treatment such as drugs that inhibit growth hormone production and surgical removal of the tumour can help avert the more serious conditions of gigantism.

The master gland in context

Where does this vitally important hormone manufacturer sit within the human brain?



"The flexibility of the cervical spine allows your head to rotate, flex and tilt many thousands of times a day"

Anatomy of the neck

Explore one of the most complex and functional areas of the human body

The human neck is a perfect blend of form and function. It has several specific tasks (eg making it possible to turn our heads so we can see), while serving as a conduit for many other vital activities (eg connecting the mouth to the lungs).

The anatomical design of the neck would impress modern engineers. The flexibility of the cervical spine allows your head to rotate, flex and tilt many thousands of times a day.

The muscles and bones provide the strength and flexibility required, however the really impressive design comes with the trachea, oesophagus, spinal cord, myriad nerves and the vital blood vessels. These structures must all find space and function perfectly at the same time. They must also be able to maintain their shape while the neck moves.

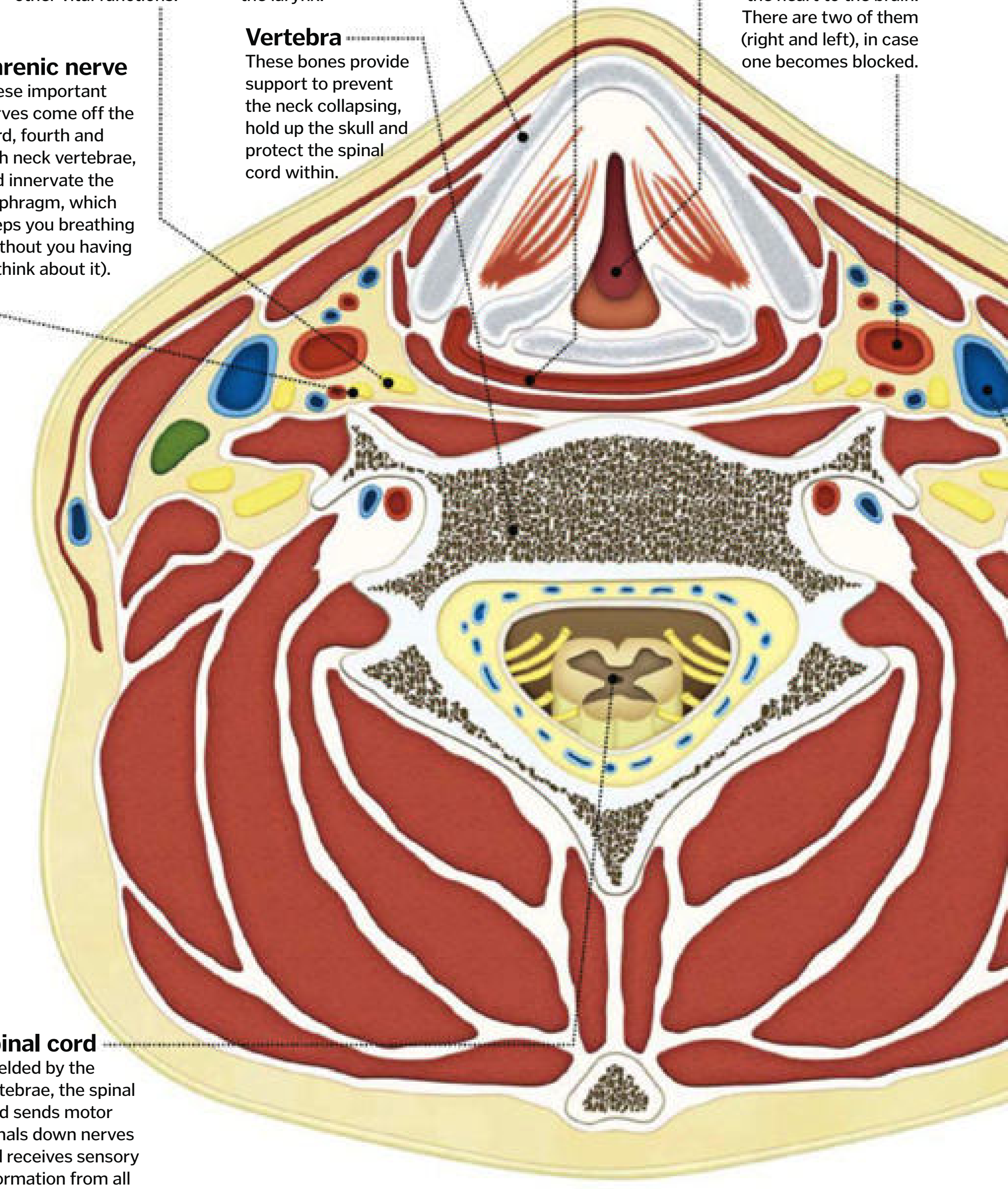
These structures are all highly adapted to achieve their aims. The trachea is protected by a ring of strong cartilage so it doesn't collapse, while allowing enough flexibility to move when stretched. Above this, the larynx lets air move over the vocal cords so we can speak. Farther back, the oesophagus is a muscular tube which food and drink pass through en route to the stomach. Within the supporting bones of the neck sits the spinal cord, which transmits the vital nerves allowing us to move and feel. The carotid arteries and jugular veins, meanwhile, constantly carry blood to and from the brain.

How does the head connect to the neck?

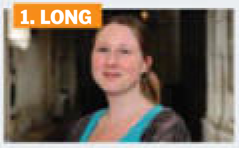
They are connected at the bottom of the skull and at the top of the spinal column. The first vertebra is called the atlas and the second is called the axis. Together these form a special pivot joint that grants far more movement than other vertebrae. The axis contains a bony projection upwards, upon which the atlas rotates, allowing the head to turn. The skull sits on top of slightly flattened areas of the atlas, providing a safe platform for it to stabilise on, and allowing for nodding motions. These bony connections are reinforced with strong muscles, adding further stability. Don't forget that this amazing anatomical design still allows the vital spinal cord to pass out of the brain. The cord sits in the middle of the bony vertebrae, where it is protected from bumps and knocks. It sends out nerves at every level (starting right from the top) granting control over most of the body.

Get it in the neck

HIW shows the major features that are packed into this junction between the head and torso



HEAD 2 HEAD
LONG NECKS



1. LONG

Human
The longest human neck ever recorded was 40 centimetres (15.8 inches) long. The average neck is closer to 10-12 centimetres (3.9-4.7 inches) in length.

2. LONGER

Sauropod
These dinosaurs probably had the longest necks of all, with up to 19 vertebrae. Extinction means they don't win the prize as the longest any more though.

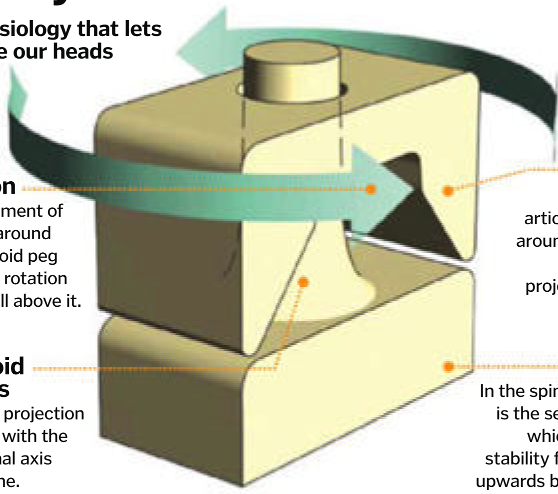
3. LONGEST

Giraffe
The giraffe has the longest neck of any land animal today. However, amazingly, it has the same number of neck vertebrae as we do – seven.

DID YOU KNOW? *The hyoid bone at the front of the neck is the only one in the body not connected to another bone*

Just say no...

The physiology that lets us shake our heads

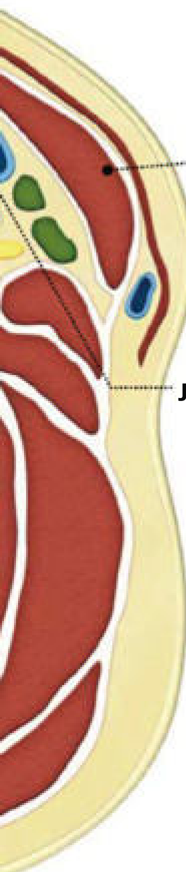


Rotation
The movement of the atlas around the odontoid peg allows for rotation of the skull above it.

Odontoid process
This bony projection is parallel with the longitudinal axis of the spine.

Atlas
This section articulates (moves) around the odontoid process which projects through it.

Axis
In the spinal column, this is the second vertebra, which provides the stability for the required upwards bony projection.

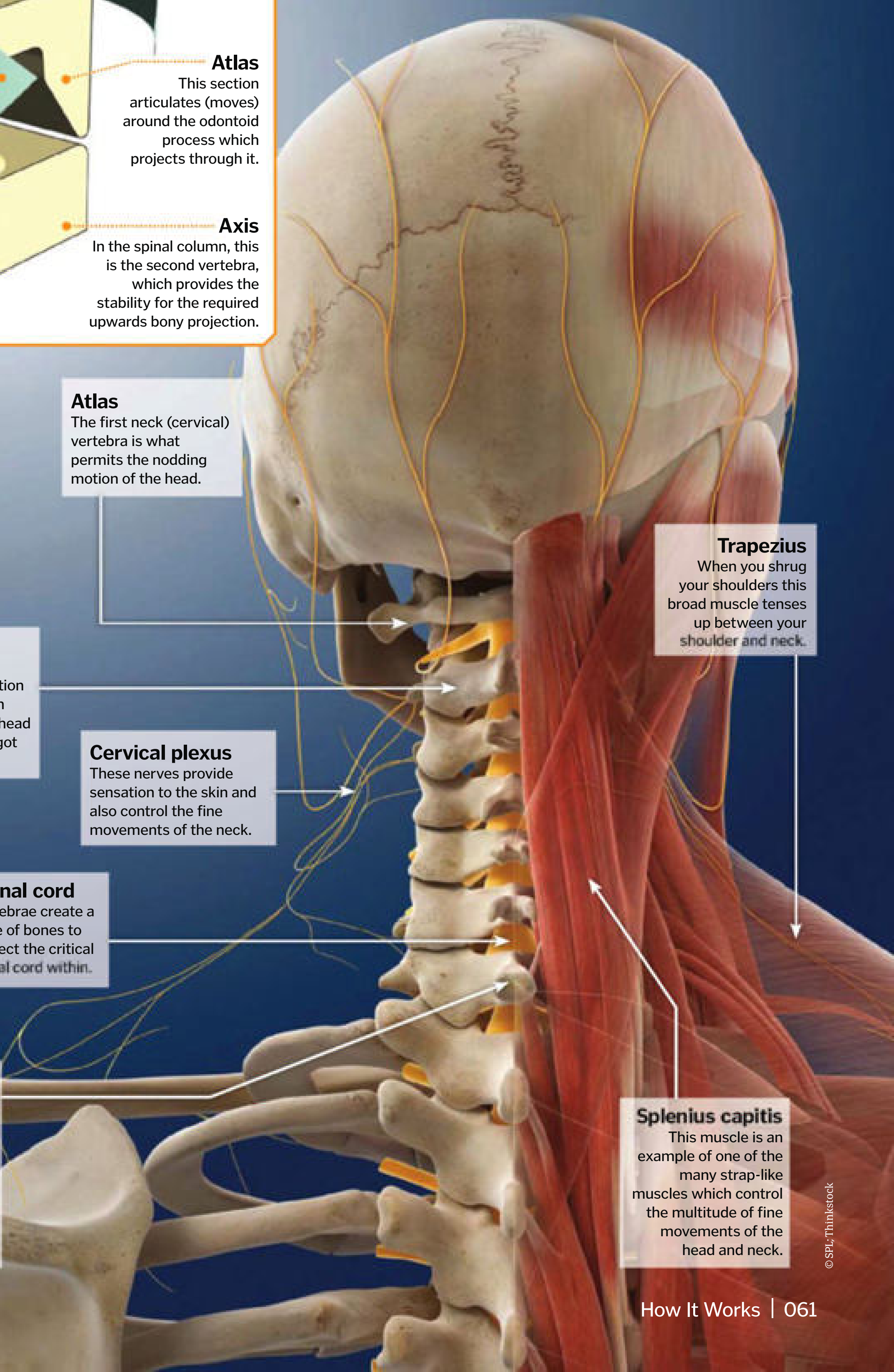


Sternocleidomastoid
Turn your head left and feel the right of your neck – this is the muscle doing the turning.

Jugular vein
These vessels drain blood from the neck, returning it to the heart.

The neck in context

The human neck relies on a wide array of bones and muscles for support, as we see here



Atlas
The first neck (cervical) vertebra is what permits the nodding motion of the head.

Axis
The second cervical vertebra allows rotation of the head. So when you're shaking your head to say no, you have got this bone to thank.

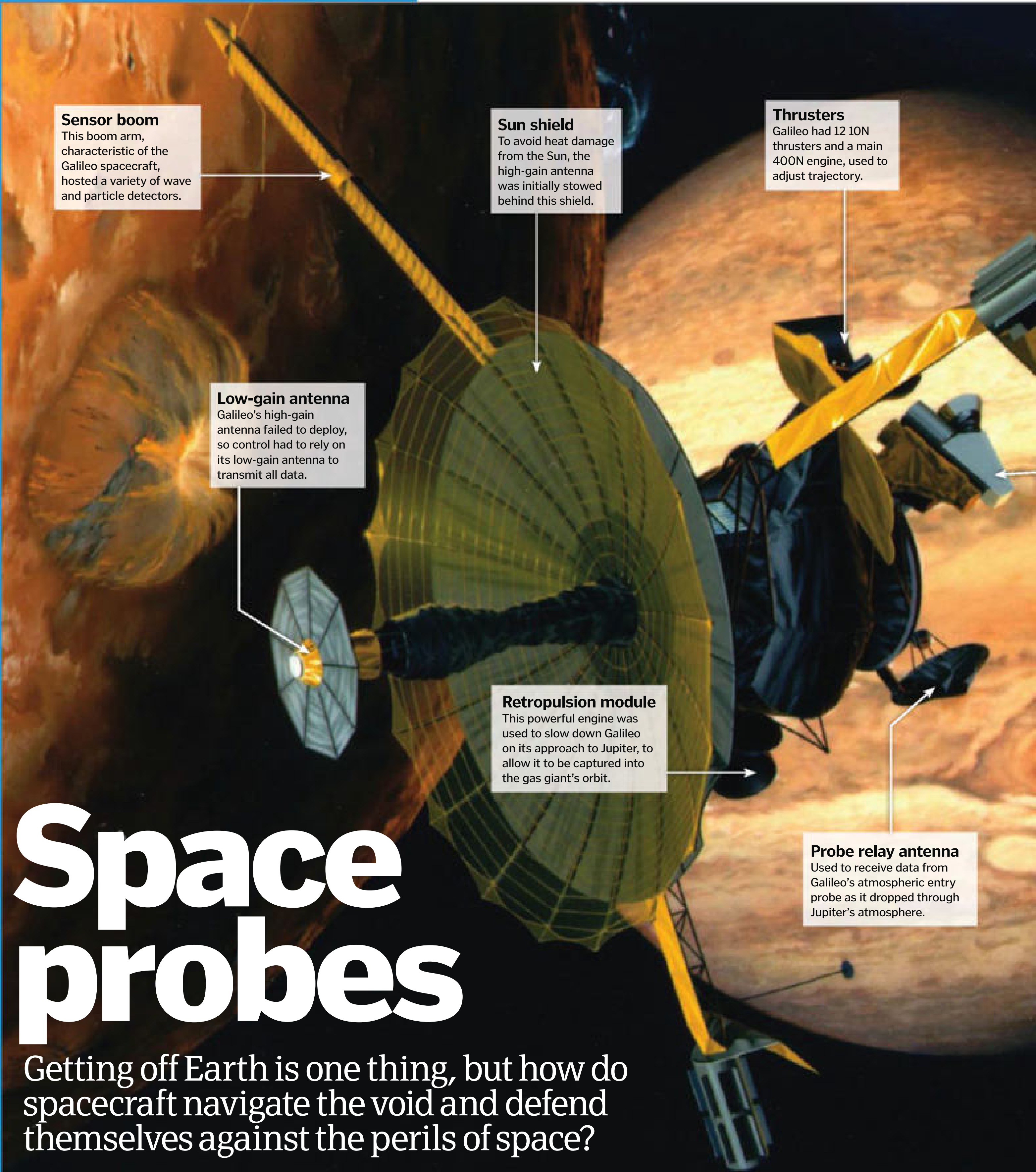
Cervical plexus
These nerves provide sensation to the skin and also control the fine movements of the neck.

Spinal cord
Vertebrae create a cage of bones to protect the critical spinal cord within.

Seventh cervical vertebra
This is the bony protuberance at the bottom of your neck, which you can feel; doctors use it as a kind of landmark so they can locate the other vertebrae.

Trapezius
When you shrug your shoulders this broad muscle tenses up between your shoulder and neck.

Splenius capitis
This muscle is an example of one of the many strap-like muscles which control the multitude of fine movements of the head and neck.

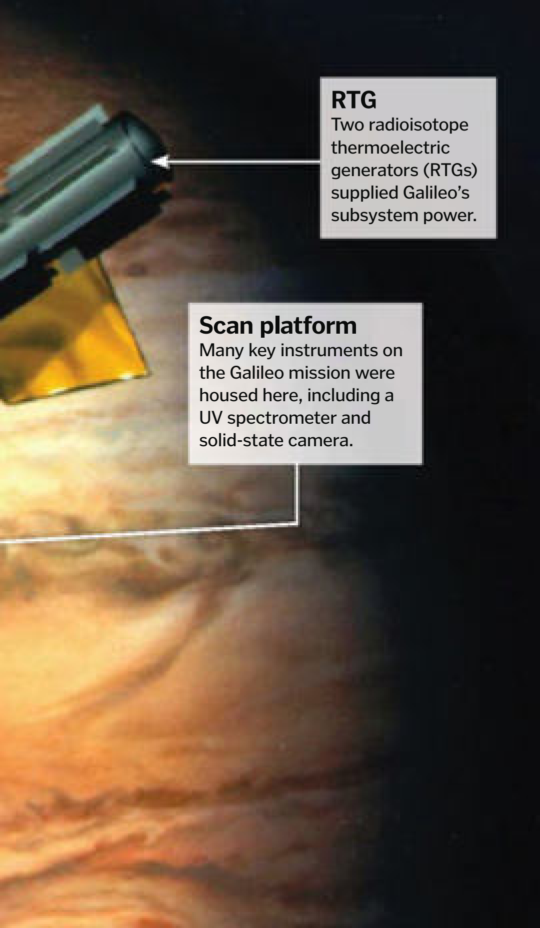


Space probes

Getting off Earth is one thing, but how do spacecraft navigate the void and defend themselves against the perils of space?

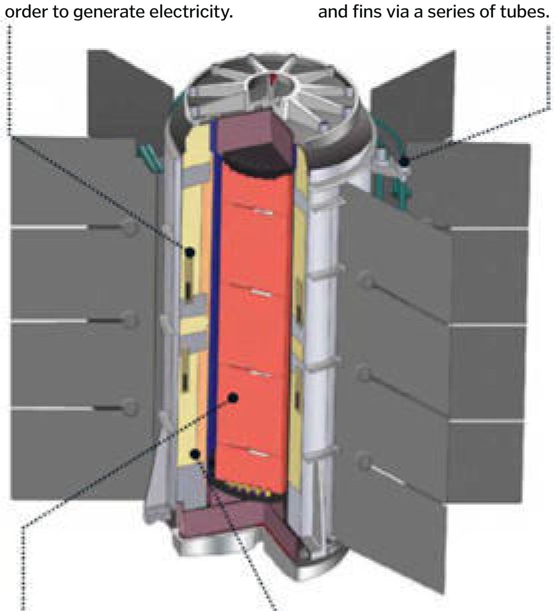
Spacecraft engineering

What technology did the Galileo spacecraft use to reach Jupiter and study it in depth?



Multi-mission radioisotope thermoelectric generators

Using the natural decay of plutonium-238 dioxide, MMRTGs are a reliable source of long-term power



The word 'spacecraft' usually evokes an image of a 'warp-speed'-travelling vessel of the future, but in the broadest definition, they're any vehicle designed for travel in space – either piloted or unmanned. In the past few decades since we've learned how to escape Earth's gravity, we've sent hundreds of spacecraft off to many of the major destinations in the Solar System, from our own Moon and the Sun, right out to dwarf planet Pluto and the very border of interstellar space.

While the Vostok manned space programme and Apollo missions to the Moon required life-support systems for the astronauts on board, sending unmanned craft into space is far from simple by comparison. Depending on the mission type and the target destination, the challenges of deep space and hazards encountered can threaten the craft's main systems or damage the sensitive science instruments it carries, potentially rendering the mission a failure.

A probe, lander, orbiter or any of the broad categories a spacecraft can fall under will house bespoke technologies specific to its mission, but they all require a power supply and energy distribution to keep their systems and instruments running. Power is a premium commodity, especially for those missions that run over decades like the Voyager and New Horizons probes. Chemical fuel cells, solar power, batteries or a radioisotope thermoelectric generator (RTG) all might be used as an energy source. Via careful monitoring both from ground control on Earth and by the spacecraft's main computer, power to any individual system can be shut down to keep the electrical outlay within the limits of the supply.

The on-board computer isn't just there to keep tabs on power though. This will process all of the data from instruments, interpret signals from mission control and, vitally, maintain several levels of fault protection, helping to prevent all manner of problems, from minor malfunctions to those that can jeopardise the entire mission. As a fundamental component of any computer, the craft will also contain a clock by which all activity is regulated. ▶

Types of spacecraft

1 Flyby
Examples: Voyager 1, Pioneer 11

These craft are on a trajectory that avoids being captured into an orbit of a planet. They have to be capable of surviving decades of travel.

2 Orbiter
Examples: Galileo, Mars Global Surveyor

Designed to reach a planet or moon and insert itself into its orbit. These are equipped with thermoregulatory systems enabling them to cope with long exposure to hot sunlight as well as extreme cold in the shade.

3 Atmospheric probe
Examples: Huygens, Galileo probe

These probes are ejected from the main spacecraft in a close approach to a planet and drop through its atmosphere on a parachute, recording and transmitting data as they go.

4 Balloon package
Examples: European Venus Explorer, Vega 1

Similar to the atmospheric probe, only it's suspended in the atmosphere with a bag of gas so it can study wind patterns and atmospheric composition over a set period.

5 Lander
Examples: Viking, Venera series

A lander also drops through the atmosphere via a powered descent or parachute. Once on the surface, it is protected from environmental extremes (like immense atmospheric pressure) to survive long enough to deploy instruments and transmit data.

"A micrometeoroid collision is like being hit by a high-velocity bullet"

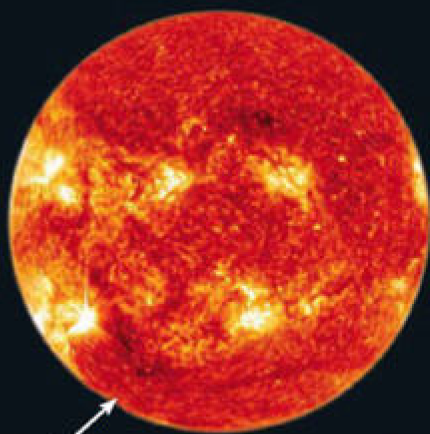
Around half a dozen subsystems control a spacecraft's propulsion, attitude and articulation. A main engine produces the force necessary for a motor burn or orbit insertion, with rocket fuel or propellant. Thrusters are much smaller devices that can nudge a craft back on course or make other correctional manoeuvres. Controlling the orientation of the craft is important not just to maintain its trajectory, but also to provide the ideal position for communicating with Earth, pointing instruments in the right direction, and to use both sunlight and shadow for thermal control.

The extreme conditions of the Solar System mean any spacecraft needs to be equipped with environmental subsystems to deal with many dangers. Colliding with an asteroid is probably of least concern: even if a spacecraft is travelling through the Asteroid Belt, there are millions of kilometres between each one so the odds of a crash are negligible.

The threat of micrometeoroids – tiny particles weighing less than a gram – is very real though. They travel at thousands of kilometres an hour and a collision with one is like being hit by a high-velocity bullet. So sensitive areas of the craft are shielded with blankets of Kevlar armour and strong fabric. The lack of atmosphere in space makes the spacecraft's systems prone to temperatures outside their range, so for thermal regulation special heaters are used as well as passive cooling with gold reflectors or white thermal blankets to deflect heat from the Sun.

Solar System explorers

Take a trip through the Solar System to learn which bodies have received the most visitors



Sun
Successful missions: 10
Major craft visited:
Ulysses, Pioneer 5-9, Genesis
While most solar craft have been used in an observational capacity, Genesis managed to take a sample of solar wind and then return to Earth.

Moon
Successful missions: 65
Major craft visited:
Apollo 11, Luna 3, Lunokhod 1
The USA had the first lunar manned mission, but Russia had the first orbiter (Luna 10) and was the first to photograph the far side of our satellite (Luna 3).

Mercury
Successful missions: 2
Major craft visited:
Mariner 10, MESSENGER
NASA's MESSENGER is Mercury's first orbiter, assembling an incredibly detailed three-dimensional map of the tiny planet in February 2013.

Venus
Successful missions: 25
Major craft visited:
Venera 7, Mariner 2, Magellan
In 1970 Russia's Venera 7 was the first successful Venusian lander and also the first successful landing on any other planet.

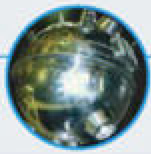
Mars
Successful missions: 26
Major craft visited:
MSL Curiosity, Mariner 4, Viking 1
Mars has become the focus of intense scrutiny because of its proximity in the inner Solar System and because of its relatively Earth-like environment.

Dealing with space radiation

As we send more probes farther into space and learn more about our Solar System, the prospect of sending manned missions beyond the Moon is becoming much more realistic. One of the biggest obstacles to this effort is how to protect astronauts from the high-energy particles found in deep space and the deadly solar winds, which contain alpha particles and protons that can destroy DNA, causing cancer. Astronauts in terrestrial orbit, such as those working aboard the International Space Station, are protected by the Earth's magnetosphere, but Apollo astronauts are thought to have got lucky in avoiding the deadly solar maximum on NASA's missions to the Moon. Recently, scientists have been working on a way of using magnets to create an artificial miniature magnetosphere 200 metres (660 feet) around a manned craft that would effectively separate the charge of the solar wind, deflecting harmful particles away. This still wouldn't protect from intergalactic cosmic rays though, meaning a safe manned mission to, say, Mars is still a way off yet.

KEY DATES
SPACE INVADERS

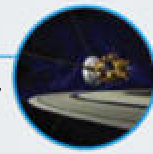
1959
The USSR's Luna 1 (right) is the first-ever spacecraft to successfully fly by the Moon.



1969
The Cold War sees a flurry of lunar orbiters, flybys and impactors, but the US lands first on the Moon.

1973
Pioneer 10 becomes the first craft to cross the Asteroid Belt into the outer Solar System and beyond.

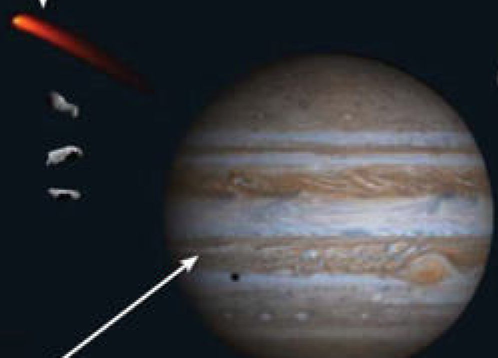
1997
Cassini-Huygens launches, and will go on to both successfully orbit Saturn (right) and land on Titan.



2007
Voyager 2 enters the heliosheath at the edge of the Solar System, having travelled 14.5bn km (9bn mi).

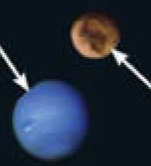
DID YOU KNOW? *Voyager 1 is right at the edge of interstellar space, about 18.5bn km (11.5bn mi) from Earth*

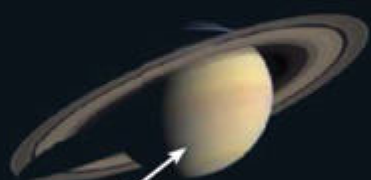
Asteroids/comets
Successful missions: 29
Major craft visited:
Dawn, NEAR Shoemaker, Deep Impact
The Asteroid Belt is home to Ceres, the only dwarf planet in the inner Solar System. The Deep Impact probe famously shot an impactor into comet 9P/Tempel 1 as it flew by to study its composition.

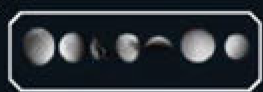


Jupiter
Successful missions: 9
Major craft visited:
Galileo probe, New Horizons, Pioneer 10
Jupiter's huge gravitational pull is used to 'slingshot' spacecraft into the outer Solar System and beyond, so it has seen many flybys.

Neptune
Successful missions: 1
Major craft visited:
Voyager 2
As with Uranus, Voyager is the only craft to have visited Neptune, taking photos of unprecedented detail before moving on to become the second-farthest man-made object from Earth – just behind its twin, Voyager 1.







Saturn
Successful missions: 5
Major craft visited: **Pioneer 11, Voyager 1, Cassini**
NASA's Cassini became Saturn's first orbiter in 2004, deploying Huygens, the ESA atmospheric probe and lander, onto Saturnian moon Titan in 2005.

Uranus
Successful missions: 1
Major craft visited:
Voyager 2
Having launched back in 1977, Voyager 2 reached Uranus in 1986 before continuing on through the Solar System. It studied the planet's dark rings and found ten new moons.

Pluto/Kuiper Belt
Successful missions: 0
Major craft en route:
New Horizons
The logistics of getting to Pluto, around 4.8bn km (3bn mi) away, are extremely challenging. Hence, New Horizons will be the first craft to reach the dwarf planet, with an estimated arrival time of 2015.

Spacecraft types cont.

6 Surface penetrator
Examples:
Mars Polar Lander, Mars 96
Surface penetrators must survive an acceleration of hundreds of 'g's through the atmosphere to punch their way into a planet, before they can begin to analyse the subsurface composition.

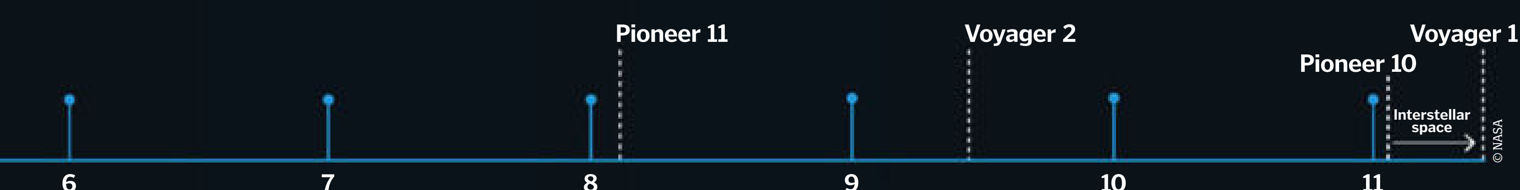
7 Rover
Examples:
Curiosity, Lunokhod 1
These are sophisticated, semi-autonomous vehicles that can move across the surface of a planet. They're dropped in a capsule so they survive descent and are fitted with many scientific instruments.

8 Manned
Examples:
Vostok 1, Apollo 11
Historically, these have been orbiters or landers installed with life-support modules to house astronauts and make the return journey to Earth. However, some proposals have included non-return craft with colonisation as a primary objective.

What is the Deep Space Network?

The establishment of the Deep Space Network (DSN) has been a critical component of many NASA missions. It's a communications system comprising three huge antennas with transceivers strategically positioned around the world: Goldstone in eastern California's Mojave Desert, Robledo de Chavela near Madrid, Spain, and the Canberra Deep Space Communication Complex in Australia. Their terrestrial position means that the collective DSN can communicate with any craft beyond a critical 30,000-kilometre (18,640-mile) threshold from Earth.

This network is used not only to relay and receive telemetry from spacecraft, but also to gather data from probes and transmit commands or software updates. It was recently used to monitor and guide NASA's Mars Science Laboratory probe onto Mars and is in frequent contact with the Curiosity rover as well as using the artificial satellite network orbiting Mars. NASA's DSN isn't the only example of such a communications network though. It often co-operates with other space agency networks, such as the Soviet Deep Space Network and ESTRACK, managed by the European Space Agency.

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EARTH'S BIGGEST DIAMOND

This record goes to the rough Cullinan diamond from which the 530-carat Star of Africa was cut. To compare, BPM 37093 is around 10 billion trillion trillion carats!

DID YOU KNOW? *A teaspoonful of white dwarf diamond is so dense that here on Earth it would weigh several tons!*

False dawns demystified

Also called 'zodiacal light', what causes this glow that can light up the night sky?

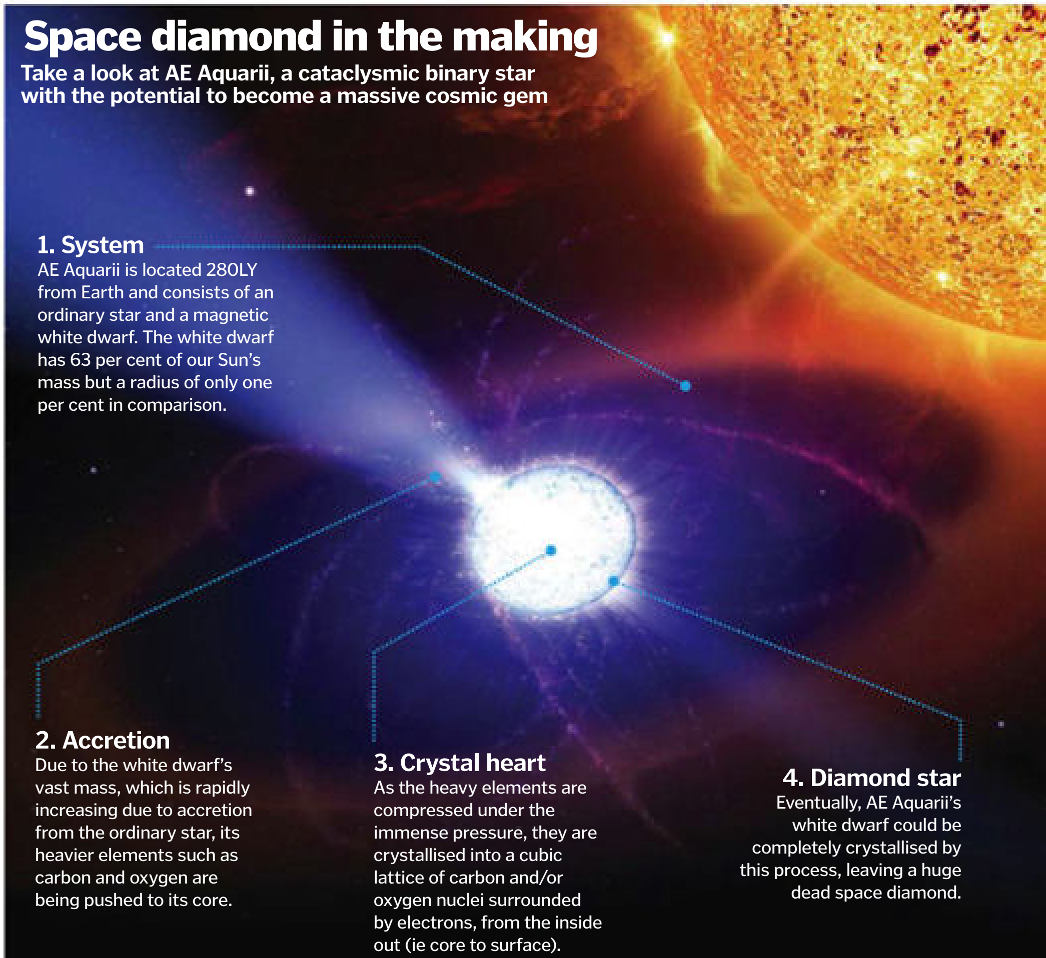
Zodiacal light is the diffuse triangular patch that can sometimes be seen in the early hours. It's so bright at certain times of year in areas with low light pollution that it can be mistaken for sunrise (hence its 'false dawn' moniker). But what causes it?

The glow is sunlight reflected and scattered across a region of interplanetary dust particles, known as the zodiacal cloud. Mostly made up of tiny debris from Jovian comets and asteroid collisions, it orbits our Sun in the same plane as the planets, spanning the inner Solar System.

Zodiacal light is only visible at certain times and places because this is when the dust band is nearly vertical at sunrise, so the thicker air viewed along the horizon doesn't block the light from the dust. Its observation has been noted in Islamic texts, as Muslims needed to recognise the phenomenon so as not to begin morning prayers at the wrong time.

Space diamond in the making

Take a look at AE Aquarii, a cataclysmic binary star with the potential to become a massive cosmic gem



Diamond stars

How do bodies like our Sun become enormous jewels?

For nearly 40 years astronomers had believed that the interiors of white dwarfs – the remnants of stars like our Sun – were crystallised carbon; that is to say, they were made of diamond. These would be truly enormous jewels – several thousand kilometres in diameter. It's only in the last few years that clear evidence for these giant cosmic gems' existence has been obtained.

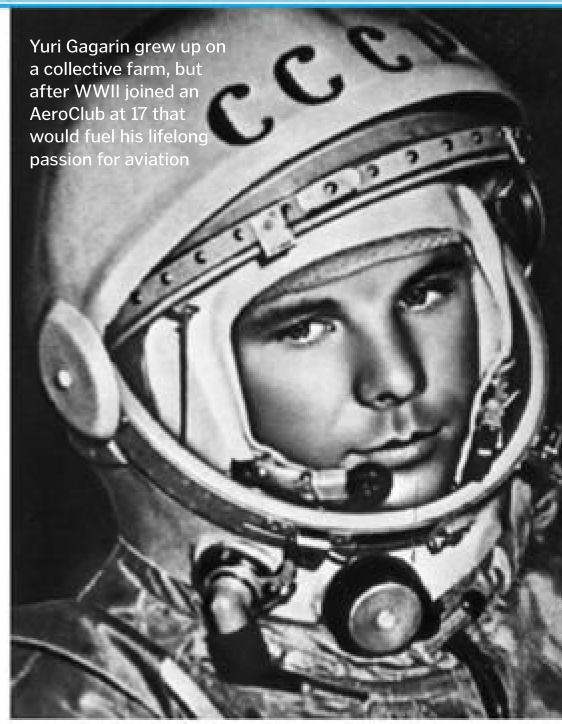
Around 50 light years from Earth in the constellation of Centaurus is the compacted heart of a dead star with the technical name BPM 37093. It no longer shines, but it does still twinkle, as a 10 billion, quadrillion-carat diamond 4,000 kilometres (2,485 miles) in diameter. Its fascinating secret was uncovered because it resonates with regular frequency and, by measuring the pulsations, scientists were able to determine the composition of its interior. It's a similar method to the way geologists can establish what's underground using a seismograph.

Our Sun will reach its white dwarf stage in about 5 billion years' time, crystallising over a further 2 billion years to become literally the jewel of our own Solar System.

MILESTONES
MARKING MOMENTOUS MOMENTS IN SPACE

First human in space

On 12 April 1961, Yuri Gagarin became the first person to enter space, paving the way for a new era of exploration


Yuri Gagarin grew up on a collective farm, but after WWII joined an AeroClub at 17 that would fuel his lifelong passion for aviation

Gagarin facts

1 Carpenter
Yuri Gagarin was the son of a carpenter and graduated from trade school as a moulder in 1951. Later he entered the Soviet Air Force.

2 20 to 1
In August 1960 Gagarin was one of 20 possible candidates for the Vostok 1 mission. He was chosen due to his all-round capabilities.

3 Been there, done that
Interestingly, after accomplishing his record-breaking feat, Gagarin never went into space again, instead retraining as a fighter pilot.

4 Sporty spaceman
Gagarin was a keen sportsman, playing hockey and basketball regularly.

5 Final flight
Gagarin died at just 34 in an unsolved accident while flying a MiG-15 training jet.

Vostok 1 was the first in a series of space missions undertaken by the Soviet Union. It consisted of a Vostok 3KA spacecraft, an R-7 Vostok-K launch vehicle (a converted intercontinental ballistic missile) and one man in a SK-1 Sokol (ie Falcon) spacesuit. That man was Yuri Gagarin and, upon the successful completion of the mission, he became the first ever person to venture into space.

The aim of the mission was simple. Fire the craft into space, orbit once around Earth and then land back in Russia. The problem was that, up until then, only a single satellite – Sputnik 1 – had been inserted into orbit by the Soviet Union, with a high number of unmanned test missions between 1957 and 1961 ending in failure. If the mission were to be a success then the launch from the Baikonur Cosmodrome (now in Kazakhstan) would have to be flawless. In addition, a series of unknowns would have to be braved, with astrophysicists unsure of how a human would react to spaceflight. Gagarin was chosen for the mission from 200 candidates due to his solid grasp of astrophysics as well as his great physical conditioning – both of which would be crucial in piloting the 3KA.

The Vostok 1 mission launched at 6.07am (Universal Time) with the booster stage firing. Two minutes later the four strapped-on boosters were jettisoned, soon followed by the protective rocket shroud covering the 3KA. Next the main rocket core stage began burning out its propellant and falling away, instigating the final rocket stage that took Gagarin into space. Just ten minutes after takeoff, the final rocket stage was released, leaving the vehicle in orbit. Gagarin reported that everything was operating normally.

The 3KA then passed over the north Pacific, before progressing past Hawaii and over the equator into the south Pacific at 6.48am. By 7.25am Gagarin and the 3KA reached the west coast of Africa, triggering the craft's automatic re-entry system, which adjusted its orientation prior to the retro engine activating.

The 3KA's re-entry engine fired over Angola, roughly 8,000 kilometres (5,000 miles) from the intended landing spot. During re-entry the 3KA jettisoned its instrument module and descended through Earth's atmosphere towards Russia. Gagarin experienced extreme forces of over 8 g and, at 7.55am, the descent module was over Russia and only seven kilometres (four miles) from the surface. The passing of this altitude caused the capsule's entry hatch to be released and its ejection seat to be fired, throwing out its occupant at high speed. Thankfully the capsule's and Gagarin's parachutes deployed and, ten minutes later, they'd both landed near Engels, Saratov Oblast.

Yuri Gagarin had taken off, flown around the world and touched down all in just 108 minutes.

"The 3KA's re-entry engine fired over Angola, roughly 8,000km from the intended landing spot"

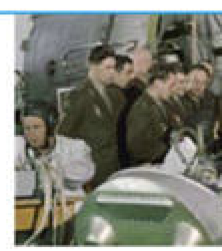
Journey to Vostok 1

How It Works takes a look at some of the key developments that led up to sending the first human into space…

1957
Sputnik 1
The world's first satellite, Sputnik 1 (right), is put into orbit by the Soviet Union. It heralds the beginning of the Space Race.

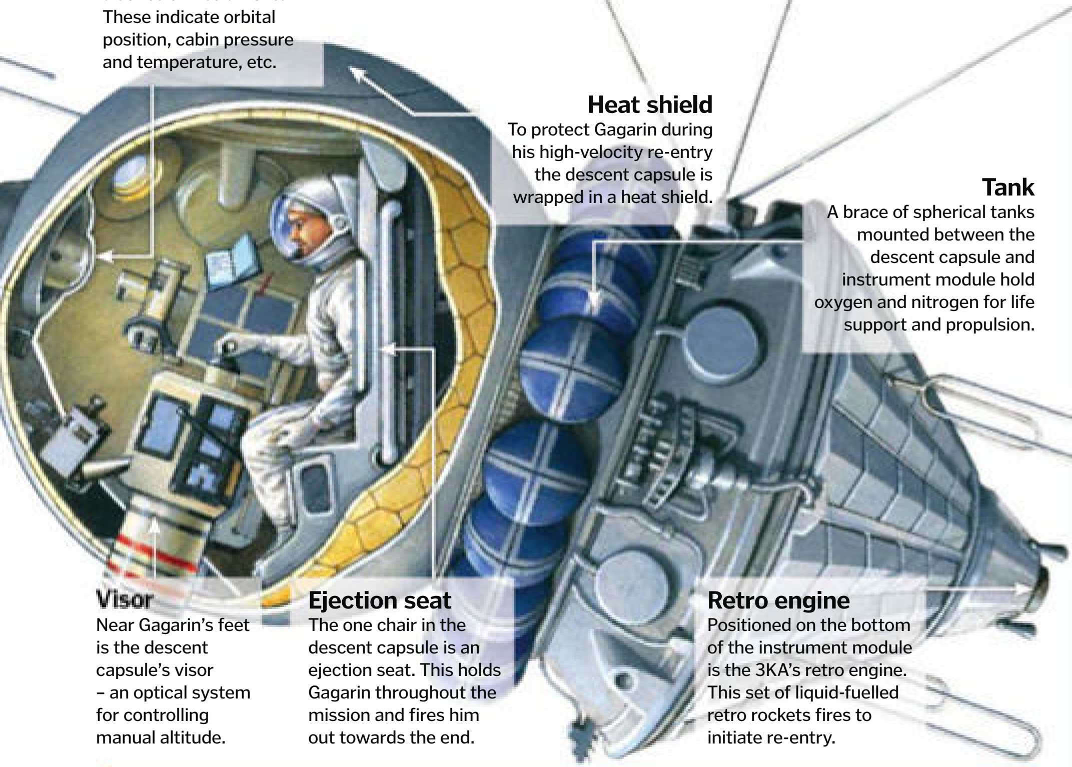
1958
Wings
After gaining his pilot wings in a MiG-15, Gagarin is assigned to the Luostari Air Base in Murmansk. He becomes a lieutenant in the Soviet Air Force.

1959
Testing times
The first stage of whittling down 200 candidates for the mission begins. The final 20 are sent for tests at the Star City training centre, near Moscow.



Vostok 3KA up close

Take a look at the craft that carried Gagarin into space



Instrumentation
Mounted to the ceiling of the descent module is a series of instruments. These indicate orbital position, cabin pressure and temperature, etc.

Heat shield
To protect Gagarin during his high-velocity re-entry the descent capsule is wrapped in a heat shield.

Tank
A brace of spherical tanks mounted between the descent capsule and instrument module hold oxygen and nitrogen for life support and propulsion.

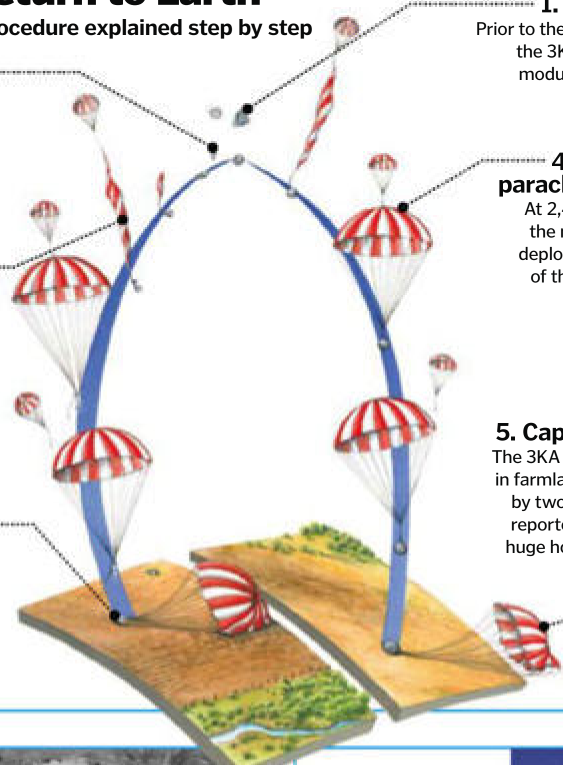
Visor
Near Gagarin's feet is the descent capsule's visor – an optical system for controlling manual altitude.

Ejection seat
The one chair in the descent capsule is an ejection seat. This holds Gagarin throughout the mission and fires him out towards the end.

Retro engine
Positioned on the bottom of the instrument module is the 3KA's retro engine. This set of liquid-fuelled retro rockets fires to initiate re-entry.

Gagarin's return to Earth

Vostok 1's descent procedure explained step by step



1. Separation
Prior to the landing phase, the 3KA's instrument module is jettisoned.

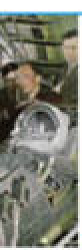
2. Hatch release
The capsule's hatch is blown off at an altitude of 7km (4mi) and Gagarin is ejected just two seconds later.

3. Gagarin's parachute deploys
Moments after Gagarin is hurled from the capsule his Falcon suit's main parachute opens.

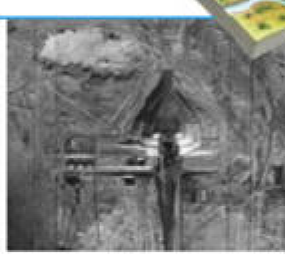
4. Capsule's parachute opens
At 2,499m (8,199ft) the main parachute deploys from the top of the 3KA capsule.

5. Capsule lands
The 3KA touches down in farmland, witnessed by two schoolgirls. It reportedly created 'a huge hole' on impact.

6. Gagarin lands
Ten minutes after Gagarin's parachute opens he lands in a farmer's field 26km (16mi) south-west of the city of Engels.



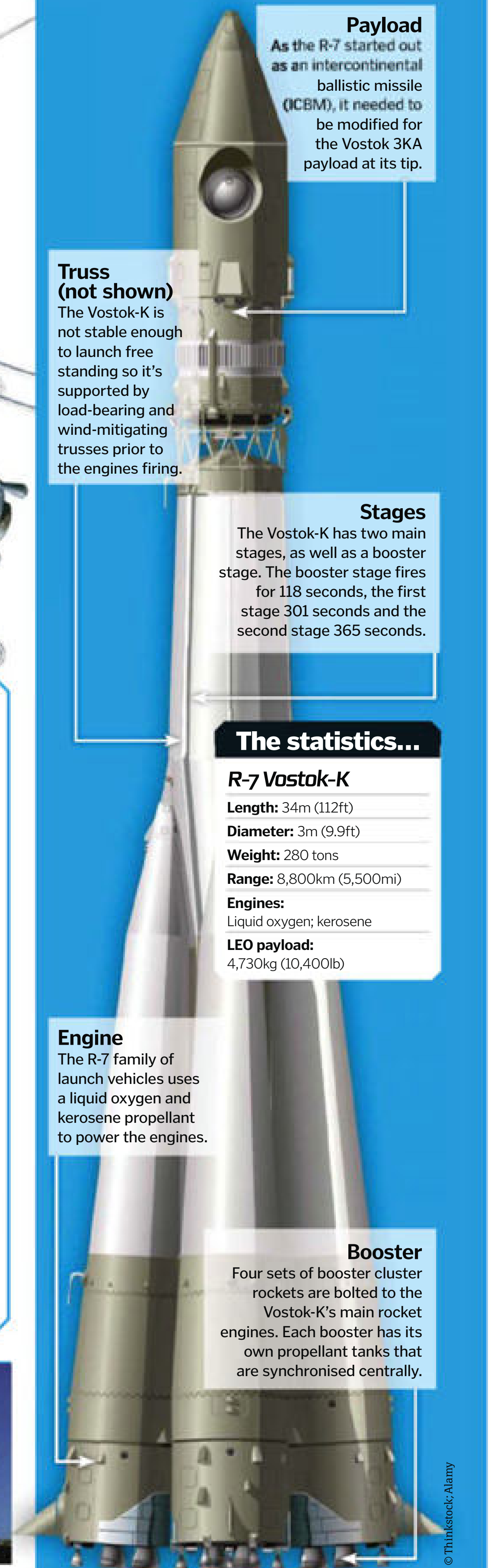
1960
Unmanned
The Soviets run a series of unmanned test flights into space from the Baikonur Cosmodrome, culminating in the successful Korabl-Sputnik 5 in March 1961.



1961
Lift-off
On 12 April, the Vostok 1 mission commences with Gagarin's 3KA spacecraft launched on the back of a Vostok-K rocket.

The R-7 Vostok-K rocket

The pioneering launch vehicle explored



Payload
As the R-7 started out as an intercontinental ballistic missile (ICBM), it needed to be modified for the Vostok 3KA payload at its tip.

Truss (not shown)
The Vostok-K is not stable enough to launch free standing so it's supported by load-bearing and wind-mitigating trusses prior to the engines firing.

Stages
The Vostok-K has two main stages, as well as a booster stage. The booster stage fires for 118 seconds, the first stage 301 seconds and the second stage 365 seconds.

The statistics...

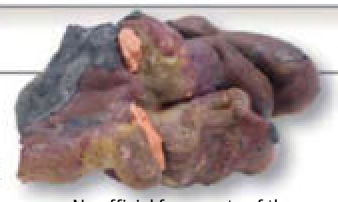
R-7 Vostok-K

Length: 34m (112ft)
Diameter: 3m (9.9ft)
Weight: 280 tons
Range: 8,800km (5,500mi)
Engines: Liquid oxygen; kerosene
LEO payload: 4,730kg (10,400lb)

Engine
The R-7 family of launch vehicles uses a liquid oxygen and kerosene propellant to power the engines.

Booster
Four sets of booster cluster rockets are bolted to the Vostok-K's main rocket engines. Each booster has its own propellant tanks that are synchronised centrally.

> "The Tunguska object was five times the size of the meteor that entered Earth's atmosphere in February 2013"



No official fragments of the object that caused the blast have been discovered, though some scientists have claimed the nearby Lake Cheko may contain some

The Tunguska event

What caused this mid-air explosion over Russia more than 100 years ago?

On the morning of 30 June 1908, the sky split in two over the forest near the Podkamennaya Tunguska River in Siberia and then a mid-air explosion rocked the area.

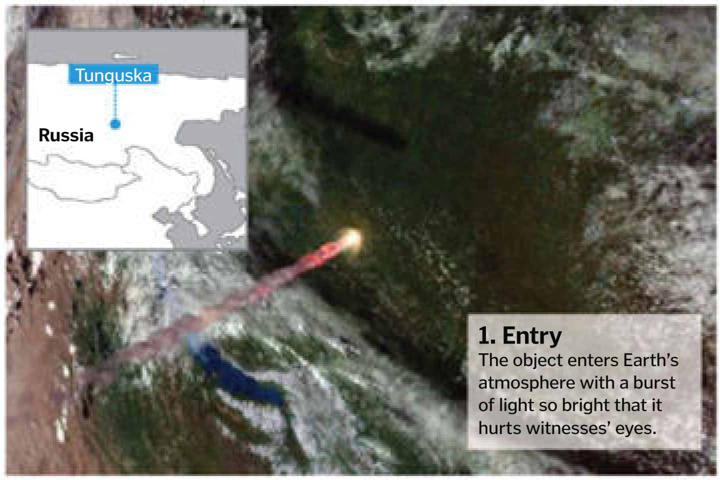
It had the estimated energy of a 15-megaton bomb – roughly a thousand times more powerful than the atomic bomb dropped on Hiroshima and millions of times more energetic than any of the man-made explosives of the day. The source of this big bang could only be extra-terrestrial.

The Tunguska event, as it later became known, was most likely a large asteroid or comet up to 100 metres (328 feet) in diameter that – going on the lack of an impact crater – exploded in mid-air about ten kilometres (6.2 miles) up. The resulting fireball and shockwave charred 100 square kilometres (38.6 square miles) and knocked 80 million trees flat in an instant.

The Tunguska object was around five times the size of the Apollo meteor that entered Earth's atmosphere and exploded over Chelyabinsk in February 2013. Objects of this size enter Earth's atmosphere only once every few centuries and the Tunguska event is one of the largest in recorded history. Despite the remote location, there were a few witnesses, who spoke of a light as bright as the Sun, followed by an explosive crack, powerful seismic tremors and a brief, unbearable heat. Indeed the scorching temperatures caused most trees to briefly char, but the proceeding shockwave blew out any flames before they could burn.

Tunguska timeline

The space rock's flight path stage by stage



1. Entry
The object enters Earth's atmosphere with a burst of light so bright that it hurts witnesses' eyes.

2. Explosion
An enormous fireball erupts as the space rock explodes 10km (6.2mi) up.

3. Devastation
Millions of trees are felled over thousands of square kilometres by a mighty shockwave even felt in neighbouring continents.

Get to know your NEOs...

What's the difference between an asteroid, comet, meteor, meteorite and meteoroid? They're not just different names for the same thing, but neither are they completely different near-Earth objects (NEOs). Comets are made mostly of rock and ice that boils off in a gas tail close to the Sun. Asteroids, meanwhile, are small, rocky carbonaceous or metallic bodies that orbit the Sun. A meteoroid is a small fragment of an asteroid or comet orbiting the Sun; a meteor is a meteoroid that enters Earth's atmosphere and burns up (ie a shooting star); and, lastly, a meteorite is a meteoroid that passes through Earth's atmosphere and survives, impacting the surface. Statistically, the larger the rock the less likely an encounter with Earth is. Objects as big as, say, the Chicxulub asteroid hit our planet only once every 100 million years or so.

ON THE MAP

Impact crater sites around the world

1. Vredefort, South Africa
2. Sudbury Basin, Canada
3. Chicxulub, Mexico
4. Woodleigh, Western Australia
5. Kara, Russia
6. Manicouagan, Canada

> "Unlike the auroras we witness here on Earth, those imaged on Saturn are not visible to the human eye"

Saturn's amazing auroras

It's like the northern lights – just 100 times more awesome…

As with the aurora borealis on Earth, Saturn's polar auroras – shot here at the planet's south pole – are generated by the collision of energetically charged particles into the planet's upper atmosphere. The difference, however, is that the auroras can streak out to an incredible height of 1,000 kilometres (620 miles) above Saturn's clouds.

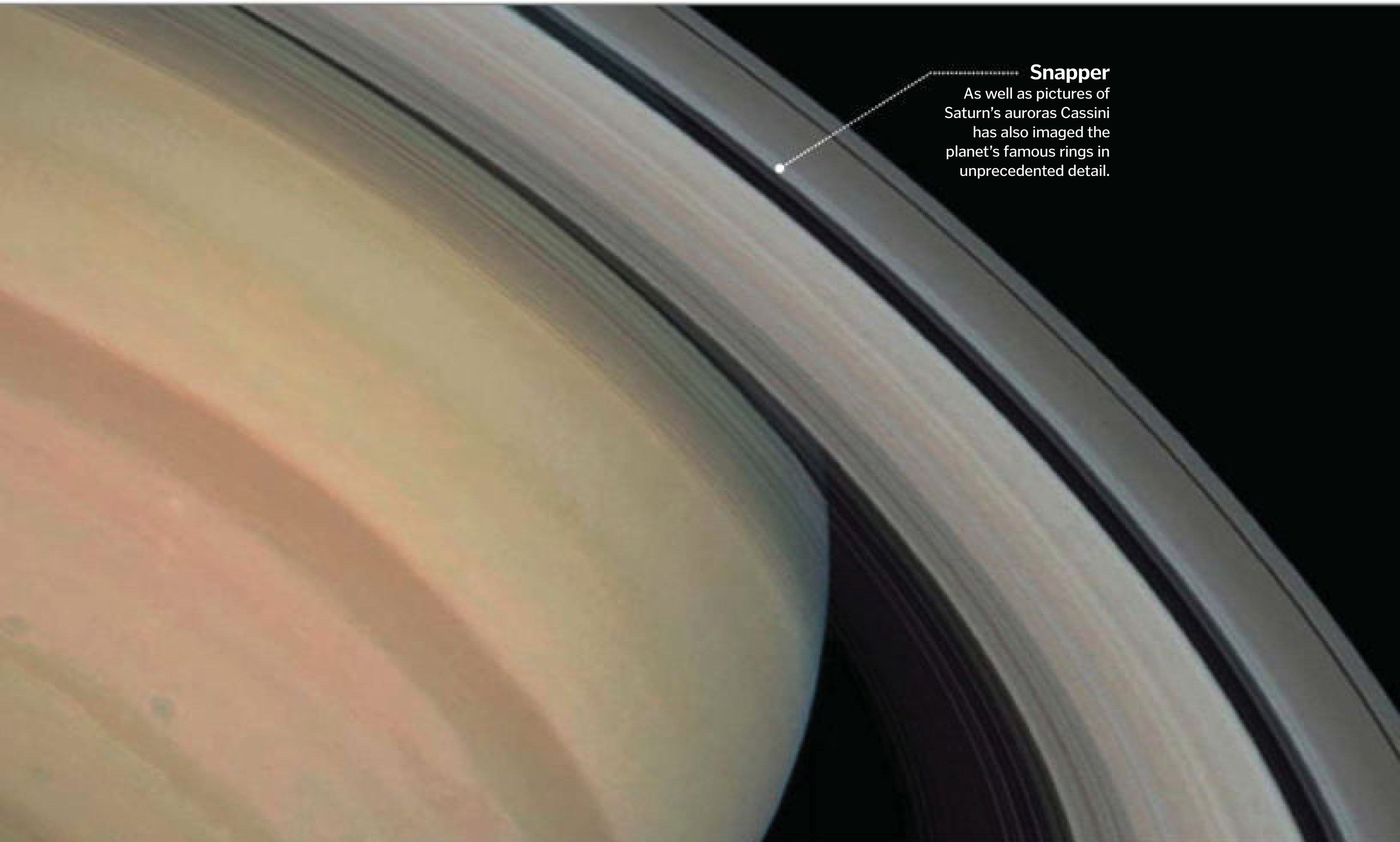
The charged particles are produced primarily by the gas giant's magnetosphere, though they are also contributed to by the bombardment of solar winds emanating from the Sun. These generated particles impact into the atomic and molecular hydrogen in Saturn's polar atmosphere, causing the gaseous atoms to ionise. Ultimately this ionisation results in photons being emitted, which combined lead to that distinctive ethereal glow.

Importantly, unlike the auroras we witness here on Earth, those imaged on Saturn are not visible to the human eye. Indeed, the aurora only glows brightly like this at about four micrometres (0.0002 inches), which is six times the wavelength visible to the human eye. The images here were captured by the Cassini space probe's Visual and Infrared Mapping Spectrometer (VIMS), which can peer deep into the infrared and ultraviolet spectrum.

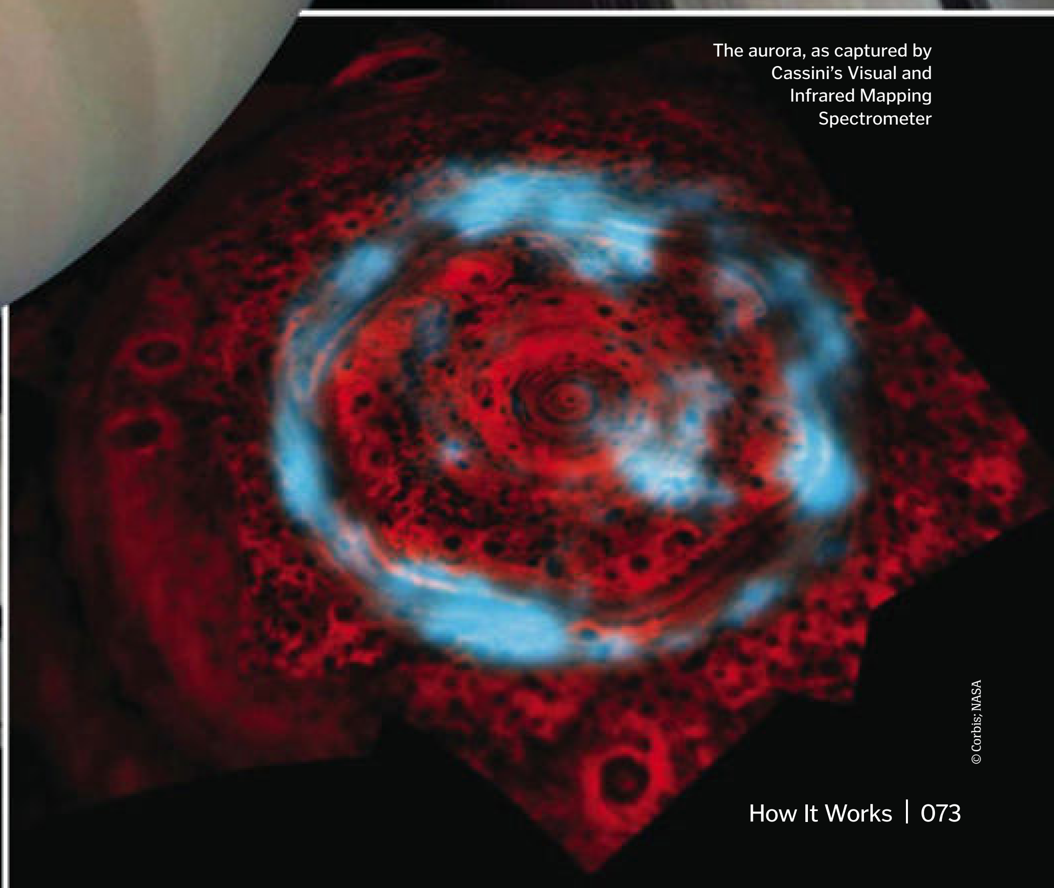
THE STATS
SATURN TRIVIA

APHELION FROM THE SUN (KM)	1.5bn
ORBITAL PERIOD (EARTH YEARS)	29.45
MASS (KG)	5.6832×10^{26}
MEAN RADIUS (KM)	58,232
ORBITAL VELOCITY	9.6km/sec
CONFIRMED MOONS TO DATE	62

DID YOU KNOW? *The light from Saturn's aurora is emitted at three to four micrometres in wavelength*



Snapper
As well as pictures of Saturn's auroras Cassini has also imaged the planet's famous rings in unprecedented detail.



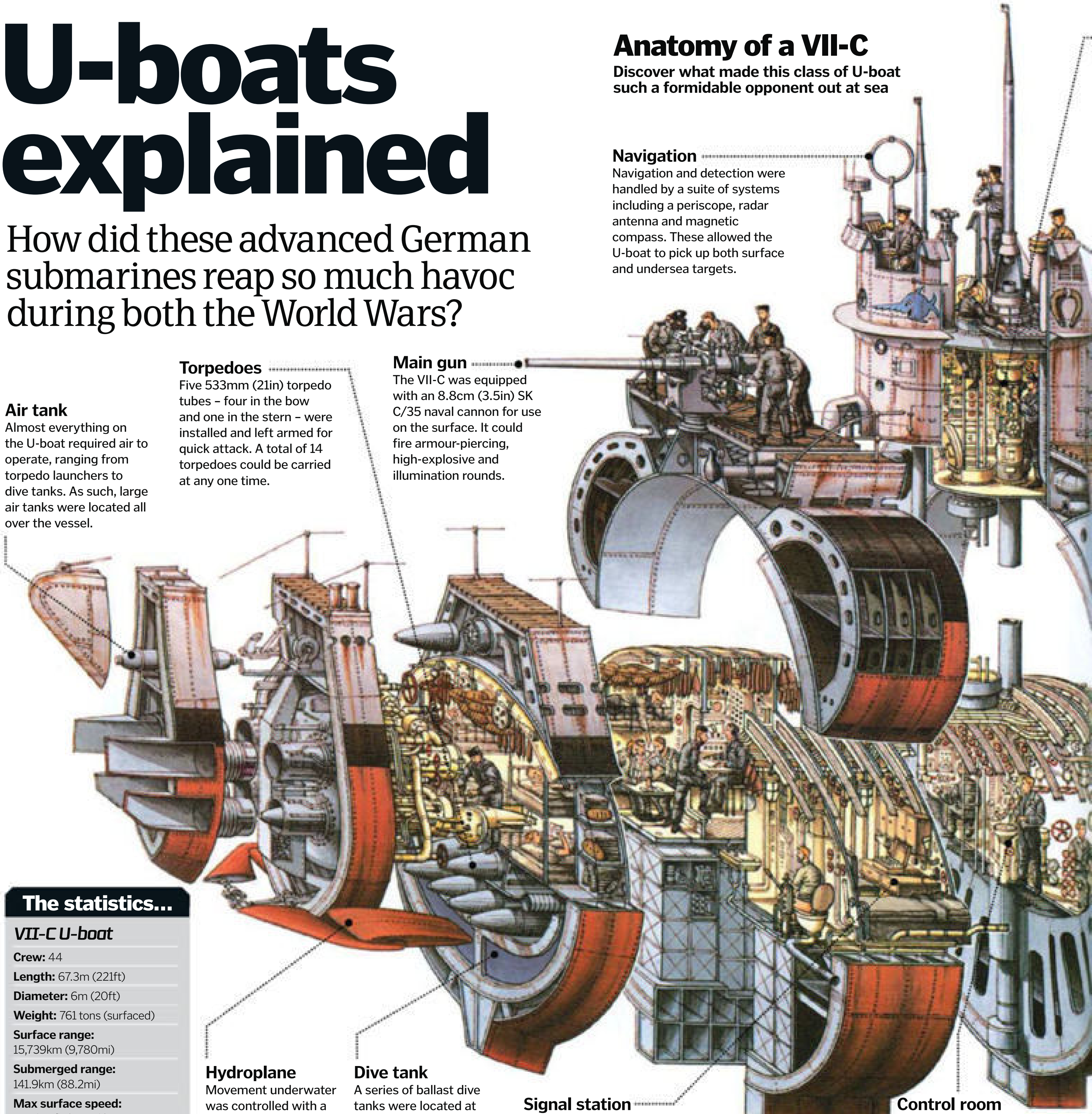
The aurora, as captured by Cassini's Visual and Infrared Mapping Spectrometer

U-boats explained

How did these advanced German submarines reap so much havoc during both the World Wars?

Anatomy of a VII-C

Discover what made this class of U-boat such a formidable opponent out at sea



Navigation
Navigation and detection were handled by a suite of systems including a periscope, radar antenna and magnetic compass. These allowed the U-boat to pick up both surface and undersea targets.

Air tank
Almost everything on the U-boat required air to operate, ranging from torpedo launchers to dive tanks. As such, large air tanks were located all over the vessel.

Torpedoes
Five 533mm (21in) torpedo tubes – four in the bow and one in the stern – were installed and left armed for quick attack. A total of 14 torpedoes could be carried at any one time.

Main gun
The VII-C was equipped with an 8.8cm (3.5in) SK C/35 naval cannon for use on the surface. It could fire armour-piercing, high-explosive and illumination rounds.

Hydroplane
Movement underwater was controlled with a series of hydroplanes – short, wing-like appendages that could be angled as desired. Facing them up caused the vessel to dive.

Dive tank
A series of ballast dive tanks were located at the lower front of the vessel. When on the surface these tanks were empty and filled with air; to submerge, they were flooded with water.

Signal station
Even when submerged up to 9m (30ft) the U-boat could still send and receive long-wave radio signals. Codes were encrypted prior to transmission.

Control room
When submerged, the centre of operations was the control room. Steering, navigation and fire commands were all issued from here.

The statistics…

VII-C U-boat

Crew: 44
Length: 67.3m (221ft)
Diameter: 6m (20ft)
Weight: 761 tons (surfaced)
Surface range: 15,739km (9,780mi)
Submerged range: 141.9km (88.2mi)
Max surface speed: 30.5km/h (19mph)
Max submerged speed: 13.5km/h (8.4mph)
Armament: 14 torpedoes; 60 mines; 8.8cm (3.5in) main gun

5 TOP FACTS
U-BOAT TRIVIA

Pack hunter
1 U-boats were famous for hunting targets in groups known as 'wolf packs', which would engage the enemy as a single deadly unit, much like the animal namesake.

Veteran
2 While U-boats were at their most numerous and advanced during World War II, early versions were used in World War I too, sinking many a military and civilian ship.

Breaking the rules
3 Despite the 1919 Treaty of Versailles forbidding the construction of submarines, by the start of World War II Germany already had 65 U-boats, with 21 battle-ready.

Atlantic standoff
4 U-boats were most heavily used in the Battle of the Atlantic, a campaign to seize control over supply routes to and from America that lasted throughout World War II.

Lone survivor
5 The only VII-C U-boat that remains intact today is model U-995. This vessel is on display at the Laboe Naval Memorial in Schleswig-Holstein, Germany.

DID YOU KNOW? *It's estimated that over 3,000 Allied ships were sunk by U-boats during WWII*

Conning tower
Each VII-C was topped with a conning tower at the centre of the vessel. The commander of the U-boat controlled the submarine from here when surfaced.

Flak cannon
A few VII-Cs were fitted with a flak cannon too. These 20mm (0.8in) guns were used to fire at any enemy attack aircraft trying to blow the U-boat out the water.

Storage
There was no dedicated storage area in U-boats due to their compact, narrow design. As such meat, bread and other produce were kept in the crew quarters.

U-boats – or 'unterseeboots', which translates as 'undersea boats' – were a series of submarines used in both World War I and World War II. They were famed for their ability to stealthily strike at Allied vessels, ganging up on them in brutally efficient 'wolf packs' to inflict the maximum damage. In World War I alone, 430 Allied and neutral ships were sunk by these roving packs.

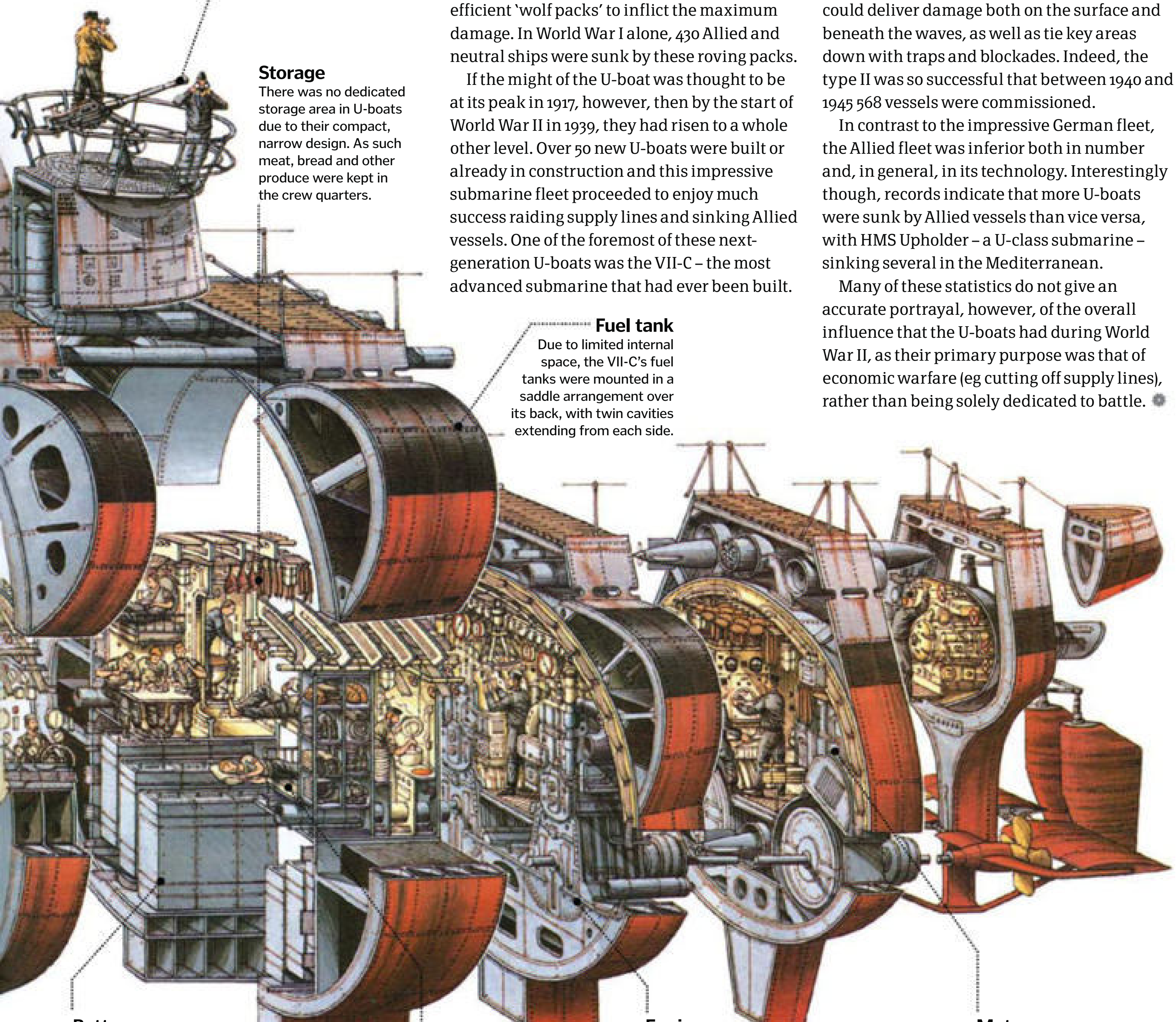
If the might of the U-boat was thought to be at its peak in 1917, however, then by the start of World War II in 1939, they had risen to a whole other level. Over 50 new U-boats were built or already in construction and this impressive submarine fleet proceeded to enjoy much success raiding supply lines and sinking Allied vessels. One of the foremost of these next-generation U-boats was the VII-C – the most advanced submarine that had ever been built.

Capable of travelling thousands of miles on the water and then able to submerge and strike enemy targets within a 142-kilometre (88-mile) range, the VII-C was the backbone of Germany's submarine fleet. Armed with a bounty of torpedoes, sea mines and cannons, the VII-C could deliver damage both on the surface and beneath the waves, as well as tie key areas down with traps and blockades. Indeed, the type II was so successful that between 1940 and 1945 568 vessels were commissioned.

In contrast to the impressive German fleet, the Allied fleet was inferior both in number and, in general, in its technology. Interestingly though, records indicate that more U-boats were sunk by Allied vessels than vice versa, with HMS Upholder – a U-class submarine – sinking several in the Mediterranean.

Many of these statistics do not give an accurate portrayal, however, of the overall influence that the U-boats had during World War II, as their primary purpose was that of economic warfare (eg cutting off supply lines), rather than being solely dedicated to battle.

Fuel tank
Due to limited internal space, the VII-C's fuel tanks were mounted in a saddle arrangement over its back, with twin cavities extending from each side.



Battery array
Huge banks of electrical batteries were located in the lower centre portion of the U-boat. These supplied energy for the motors and lights.

Crew quarters
Living quarters were situated throughout the vessel. Up to 44 people could be accommodated, with individuals sleeping on narrow, wall-mounted bunk beds.

Engine
When on the surface, the U-boat was propelled by two supercharged six-cylinder, four-stroke M6V 40/46 diesel engines. These generated a maximum 2,400kW (3,200hp).

Motors
While submerged the U-boat was propelled by a brace of electric motors that produced 560kW (750hp). These were needed as the diesel engines required air to operate.

"Lodestones were the world's first compasses, with their name derived from the term for 'leading stone'"

Chainmail explained

How was this distinctive armour manufactured for protecting warriors on the battlefield?

Chainmail was made by linking together thousands of small metal ringlets. These ringlets were forged from tiny strips of iron and later steel, with the rings joined in a specific pattern and then closed by pressing, welding or riveting.

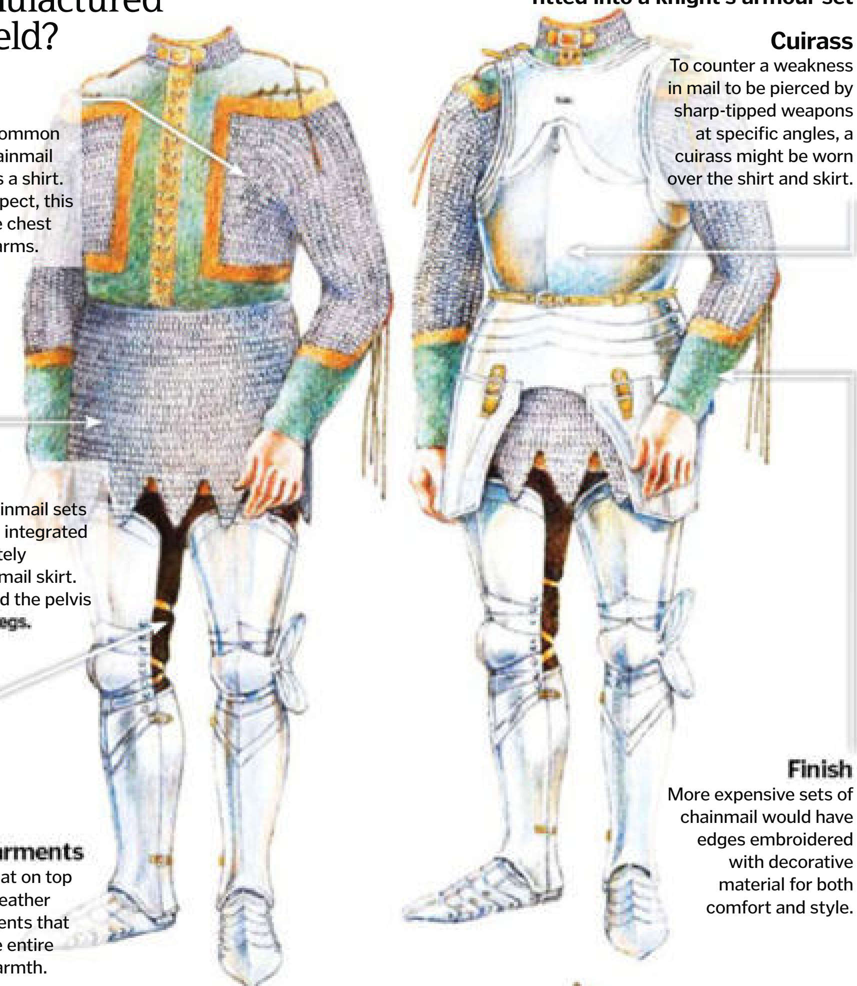
The pattern the ringlets were linked in determined the type of mail that was produced. The popular four-in-one design (ie each non-edge ring connecting to four other rings) typified European mail, while six-in-one patterns were more common in Asian mail.

The size of the rings – both in diameter and width – was also important, with larger rings covering a bigger area with less material (and therefore being lighter), yet having a coarse finish. Smaller diameter rings, on the other hand, granted a finer finish and a stronger mesh, but would weigh in considerably more.

The major benefits of chainmail over the solid cuirasses which had been worn in battle prior to its invention were a greater degree of movement for its wearer as well as more extensive coverage (ie arms were protected too). However, chainmail also suffered from a notable weakness in that sword and spear tips, or arrow heads, could penetrate individual ringlets at a direct-on angle. As such, knights would commonly wear a cuirass over the chainmail shirt for extra protection.

Chainmail in context

Discover how a suit of mail fitted into a knight's armour set



Shirt
The most common piece of chainmail armour was a shirt. As you'd expect, this covered the chest and upper arms.

Skirt
Certain chainmail sets featured an integrated – or separately attached – mail skirt. This covered the pelvis and upper legs.

Undergarments
Chainmail sat on top of cloth or leather undergarments that covered the entire body for warmth.

Cuirass
To counter a weakness in mail to be pierced by sharp-tipped weapons at specific angles, a cuirass might be worn over the shirt and skirt.

Finish
More expensive sets of chainmail would have edges embroidered with decorative material for both comfort and style.

Learn about lodestones

Find out what these natural compasses are all about…

A lodestone is a piece of the mineral magnetite – a highly magnetised substance – that when suspended orientates itself with the direction and polarity of Earth's magnetic field. Due to this innate ability, lodestones were used as the world's first compasses, with their current name derived from the Middle English term for 'leading stone'.

Not all magnetite is naturally magnetised however, with only a small amount of the mineral – which is largely found in Earth's crust – able to be used as a lodestone. Indeed, research suggests that only strains of magnetite with a specific crystalline structure has the necessary coercivity (resistance to being demagnetised) to be utilised as a navigational aid.

NASA scientist Dr Peter Wasilewski believes lodestones are created by the introduction of lightning discharges to magnetite. While short-lived a lightning bolt could create a very strong magnetic field capable of magnetising the mineral.

KEY DATES
BUILDING LONGMEN

493 CE The Northern Wei Dynasty begins building work with Guyangdong, the Old Sun Cave.

524 After a hiatus in activity, the second stage starts as the Longmen Grottoes are extended.

675 The third phase occurs in the Tang Dynasty, with the construction of the Fengxiansi Cave.

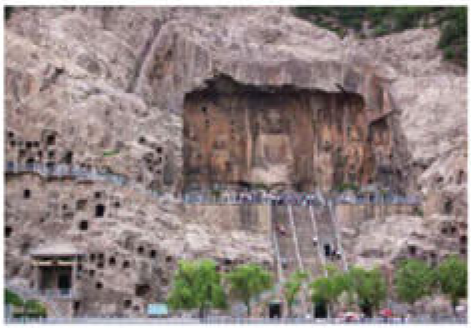
1368 The Ming Dynasty sees Longmen achieve national recognition after a long period of cultural decline.

1953 China's Ministry of Culture establishes the Longmen Relics Care Agency to look after the Buddhist site.

DID YOU KNOW? Some of the cures found in the medical prescription cave are still used in Chinese medicine today

Exploring the statues of the Longmen Grottoes

Who was behind these ancient works of art and why were they created?



A UNESCO World Heritage Site since 2000, the Longmen Grottoes are one of China's most treasured cultural attractions. The site comprises a series of caves and Buddhist statues etched out of the limestone cliffs, extending for around one kilometre (0.6 miles) either side of the River Yi, south of the city of Luoyang, Henan province.

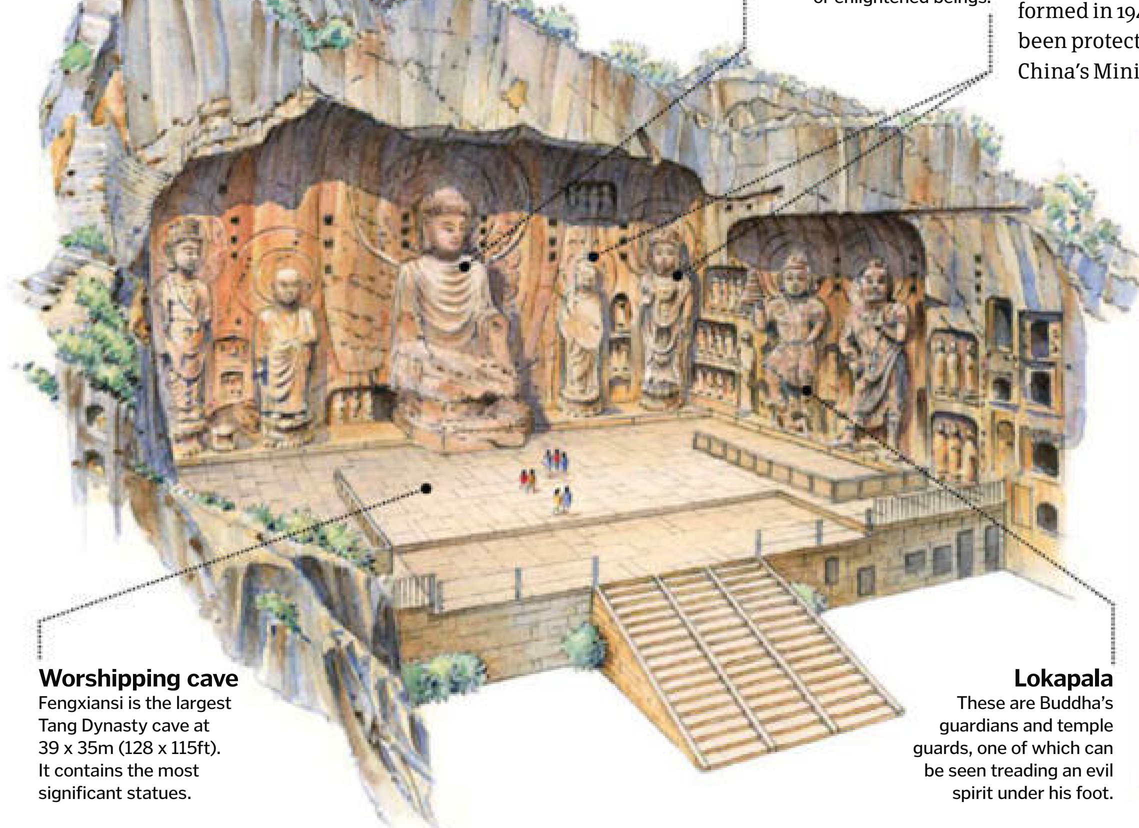
They were originally carved by the Northern Wei Dynasty over 1,500 years ago in 493 CE, though the work continued over the following six centuries through several other dynasties, until civil war in the 12th century brought the project to an end. During that time some 2,345 grottoes were created containing 2,500 inscriptions, 60 pagodas and over 100,000 statues ranging in height from just a few centimetres to a whopping 17 metres (57 feet).

The creation of the Longmen Grottoes is characterised by four distinct phases, reaching its artistic peak in the seventh century during the Tang Dynasty, when Chinese Buddhism experienced a boom in popularity. It's during this era that the elaborate Fengxiansi Cave with its giant statues were made (see illustration).

While there were long periods of neglect when no further carving took place and the Longmen Grottoes were left to ruin, no vandalism of any significance took place until the 20th century – notably by Japanese looters during the Second Sino-Japanese War (1937-1945). Since the People's Republic of China was formed in 1949, the ancient religious site has been protected as a national monument by China's Ministry of Culture.

Fengxiansi in focus

A quick tour around the most famous cave at the Longmen Grottoes site



Vairocana Buddha
This statue is the biggest at the Longmen Grottoes. Finished in 676 CE, it stands 17m (57ft) tall.

Disciples and bodhisattvas
Either side of the Vairocana Buddha are two principal disciples and bodhisattvas, or enlightened beings.

Worshipping cave
Fengxiansi is the largest Tang Dynasty cave at 39 x 35m (128 x 115ft). It contains the most significant statues.

Lokapala
These are Buddha's guardians and temple guards, one of which can be seen treading an evil spirit under his foot.

Preserving Longmen

Though a large proportion of the Longmen Grottoes remains free of vandalism, the fact it's carved from soft limestone makes it very vulnerable to weathering. A thousand years as a limestone sculpture is a long time when you're exposed to the elements, and some of the carvings have lost a lot of their detail over that time.

For the last 60 years or so, efforts have been made to protect and even restore these relics. An itinerary was first made before a weather-monitoring station was created to establish the atmospheric conditions in the area. Restoration followed in the form of clearing vegetation from the rocks and paths, building walkways and railings and, most importantly, preventing water seeping through the rock and eroding the sculptures by strengthening their plinths.

"The central living area was a room with various uses, including sleeping, cooking, craftwork and storage"

What was inside a Celtic roundhouse?

HIW reveals how these iconic buildings were built and used

Contrary to many historical sources, the Celtic people were – in many ways – a very civilised and advanced group of tribal societies. Despite their barbarous reputation in warfare, in a domestic setting they were far from primitive, employing many farming, construction and trade practices that were cutting edge for the time.

Perhaps one of the most notable examples of their forward-thinking culture can be seen in their distinctive dwellings. Celts typically lived in roundhouses, which were – as the name suggests – circular. These houses were cone shaped and able to accommodate a large number of occupants. The roundhouses were built out of wood and – later in the civilisation's development – stone, with conical thatched roofs and wattle walls standard elements.

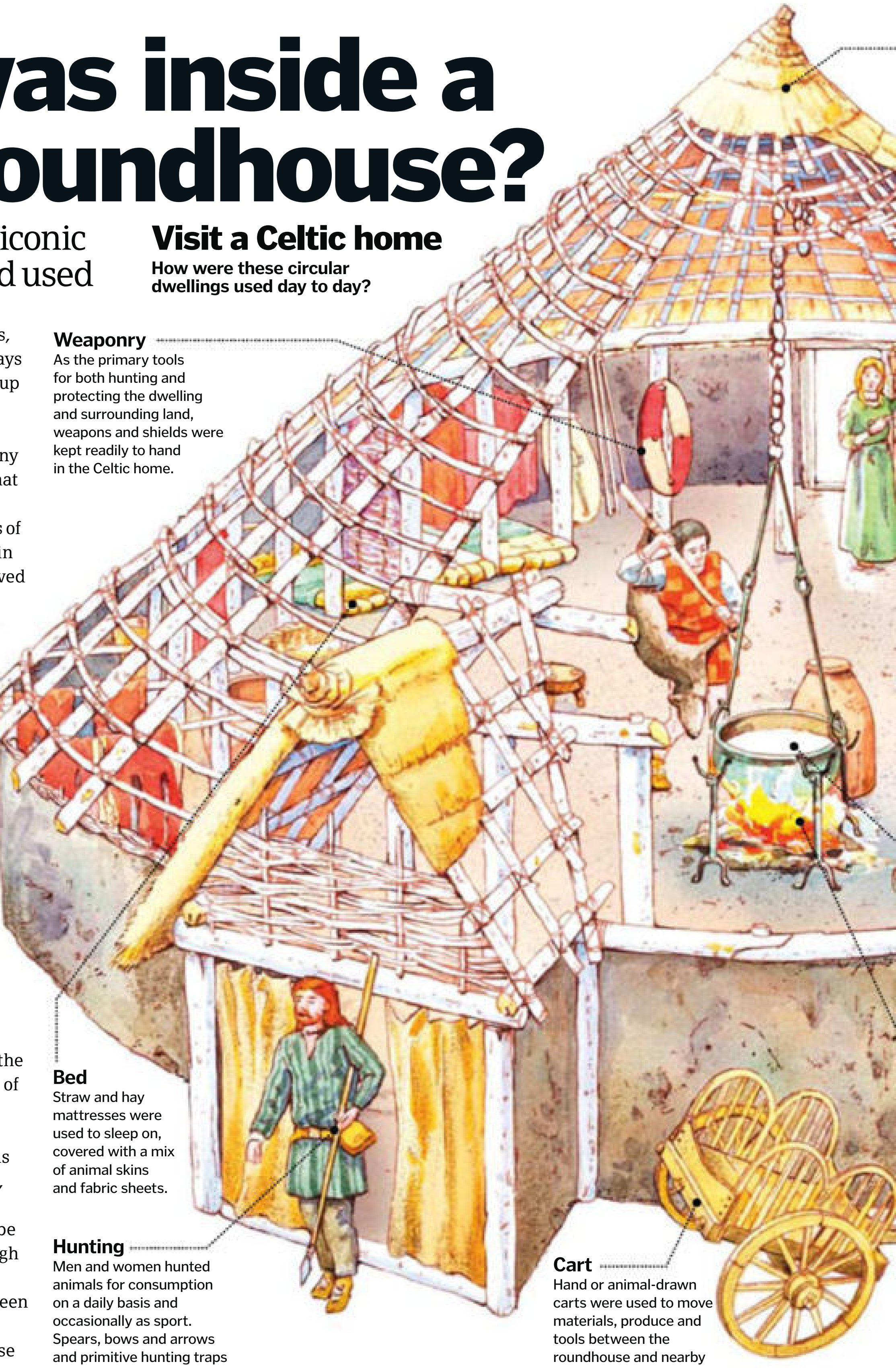
These structures were generally accessed through a single entrance, which extended out from the main structure via a porch-style chamber. This design feature provided a degree of insulation between the main living space and the worst of any cold wind and rain, with usually only sheets/animal hides used to serve as a front door.

The central living area was a single room with various uses, including sleeping, cooking, craftwork and storage. If the tribe was particularly wealthy, then a series of other auxiliary buildings would be used to house their livestock – the Celts commonly would keep sheep, pigs and cattle – as well as sizable crop yields after the harvest; indeed, Celts were highly skilled farmers all round.

Today, many Celtic roundhouses can still be found throughout Europe and beyond, though for the most part they're in a ruinous state. Many modern simulations, however, have been made using traditional Celtic construction materials and techniques, with many of these open for visits by the public.

Visit a Celtic home

How were these circular dwellings used day to day?



5 TOP FACTS
CELTIC TRIVIA

European roots
1 Over time the ancient Celts expanded out of their core homeland in central Europe. Many rich grave finds have been unearthed in this region – particularly in Austria.

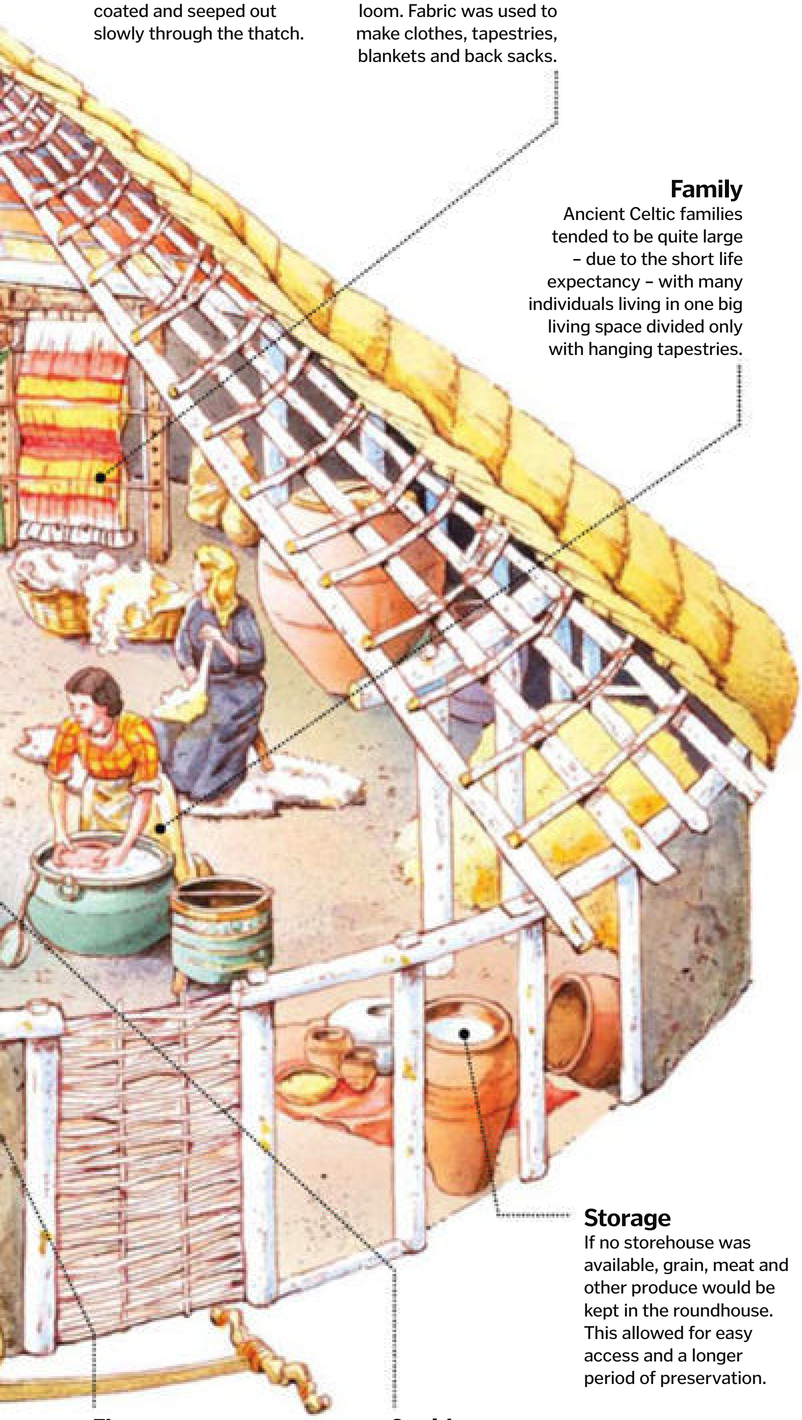
Celts at their peak
2 Celtic expansion is believed to have reached its pinnacle in the 3rd century BCE, with large parts of Spain, France and Britain colonised by various tribes and groups.

Celts in decline
3 These Celtic tribes were, in general, either defeated or absorbed with the expansion of the Roman Empire. A group of Celtic warriors did, however, sack Rome circa 390 BCE.

Heads-up
4 The Celts were notorious for headhunting, decapitating foes and, post embalming, storing them as trophies and status symbols. The head was thought to contain the soul.

Linguistic heritage
5 The language of the ancient Celts survives to this very day in the modern Celtic speakers of several areas, including Brittany, Scotland, Ireland and the Isle of Man.

DID YOU KNOW? *Remains of ancient Celtic people have been found in Transylvania, Romania*



Roof cap
There were no chimneys in roundhouses and, as such, smoke from the central fire coated and seeped out slowly through the thatch.

Loom
Fabric was created by the weaving of yarn and thread on a manual loom. Fabric was used to make clothes, tapestries, blankets and back sacks.

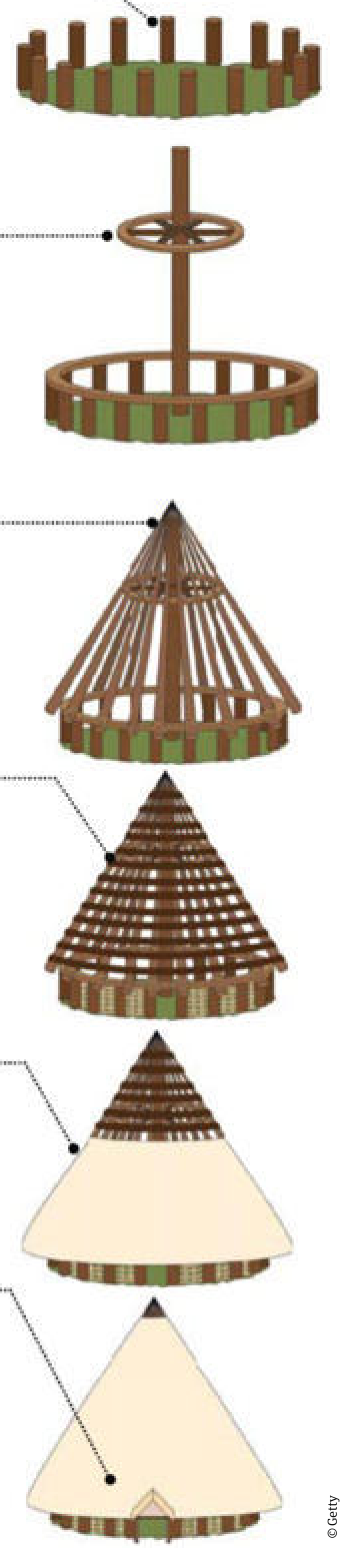
Family
Ancient Celtic families tended to be quite large – due to the short life expectancy – with many individuals living in one big living space divided only with hanging tapestries.

Storage
If no storehouse was available, grain, meat and other produce would be kept in the roundhouse. This allowed for easy access and a longer period of preservation.

Fire
A fire served as both a vital source of heat and also a means of cooking. In larger dwellings an iron fire dog – a supporting instrument for spit roasting – would have sat either side.

Cauldron
The Celts were fond of boiling fare such as game, beef and fish, along with root vegetables. This was often done in a central large cooking cauldron.

Roundhouse construction step-by-step



1 Wall posts
The roundhouse was started by workers clearing and levelling a patch of land and then knocking a ring of wall posts into the ground. These were driven manually into the earth with large mallets. The individual posts were then cut and carved.

2 Lintels and brace
Next the wall posts were linked together via supporting wooden lintels. These secured the ring layout and also provided a support for the rafters. A roof brace was also set in position via a central supporting strut. (The strut was eventually removed after installation of the rafters.)

3 Rafters
The rafters of the dwelling were added next. These were long wooden poles tied together with rope. Rafters were assembled in a conical shape, with the bottoms of the poles affixed to the wall post lintels and the tops forming a point via the roof brace.

4 Wattle and purlins
With the rafters attached, they were then covered with a series of purlins – horizontal wooden beams that wrapped around the roof. These purlins provided a solid base for the thatch to be added. Prior to thatching, however, the gaps between wall posts would be linked with wattle screens.

5 Thatch roof
The roof of the roundhouse was then covered with thatch and daub – the latter a clay/mud mix that helped bind and enhance the roof's waterproofing capability. The thatch comprised various reeds and straw.

6 Entranceway
Lastly, a porch-like entrance was built out from the doorway. This connecting chamber was a useful addition as it prevented cold air from entering directly into the main living space. The doorframe was often carved with symbolic decoration.

"The Sabre was one of the first military jets capable of firing guided air-to-air missiles"

The ferocious F-86 Sabre

Considered the foremost military aircraft of the Fifties, the F-86 Sabre was a highly versatile fighter jet as fast as it was lethal

The F-86 Sabre was a single-seat fighter jet built by North American Aviation (now part of Boeing) in the late-Forties. The aircraft – the first western jet to feature swept wings, as well as one of the first capable of breaking the sound barrier in a dive – saw action throughout the Korean War and Cold War.

Built initially to combat the Russian MiG-15, the Sabre was geared towards flight superiority roles, dispatched to undertake furious high-speed dogfights. Though inferior to the Russian jet in terms of lightness and weaponry, the reduced transonic drag delivered by the swept wings – combined with its streamlined fuselage and advanced electronics – granted it far superior handling. This ability to outmanoeuvre the MiG-15 soon saw it establish supremacy in combat.

Despite overall armament inferiority to its rivals, the Sabre was one of the first military jets capable of firing guided air-to-air missiles and later variants, such as the F-86E, were fitted with radar and targeting systems that were revolutionary for the time. These factors, along with its high service ceiling (ie maximum altitude) and its generous range of around 1,600 kilometres (1,000 miles), therefore enabled it to intercept any enemy aircraft with ease.

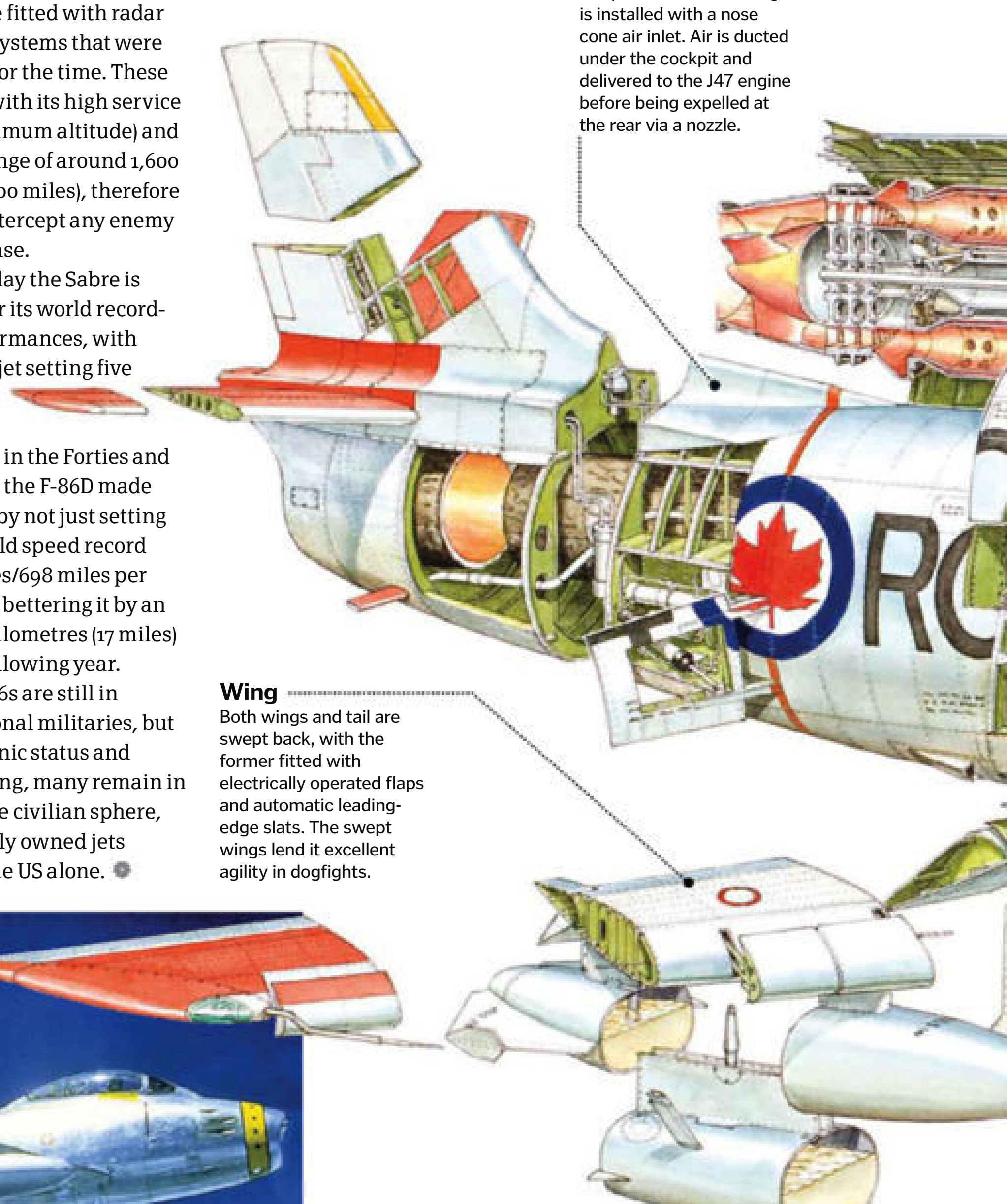
However, today the Sabre is most known for its world record-breaking performances, with variants of the jet setting five official speed records over a six-year period in the Forties and Fifties. Indeed, the F-86D made history in 1952 by not just setting the overall world speed record (1,123 kilometres/698 miles per hour), but then bettering it by an additional 27 kilometres (17 miles) per hour the following year.

Today no F-86s are still in service in national militaries, but due to their iconic status and reliable handling, many remain in operation in the civilian sphere, with 50 privately owned jets registered in the US alone.

Although built in North America at least 20 other countries used Sabres in their air forces, including Japan, Spain and the UK

On board the F-86E

Explore the advanced engineering that makes the Sabre such a formidable fighter jet…



1,151km/h

SPEED DEMON

The F-86 Sabre has broken the world speed record not once but three times, the fastest of which was in 1953 when it reached a zippy 1,151 kilometres (715 miles) per hour.

DID YOU KNOW? US production of the F-86 Sabre ended in December 1956

Engine
The F-86E uses a GE J47-13 turbojet engine capable of outputting 2,358kgf (5,200lbf) of thrust. This raw power grants it a top horizontal speed of about 1,050km/h (650mph).

Cockpit
The F-86E is fitted with a small bubble canopy cockpit that covers a single-seat cabin. The cockpit is in a very forward position, tucked just behind the nose cone.

The statistics…

F-86E Sabre

Length: 11.3m (37ft)

Wingspan: 11.3m (37ft)

Height: 4.3m (14ft)

Max speed: 1,046km/h (650mph)

Range: 1,611km (1,001mi)

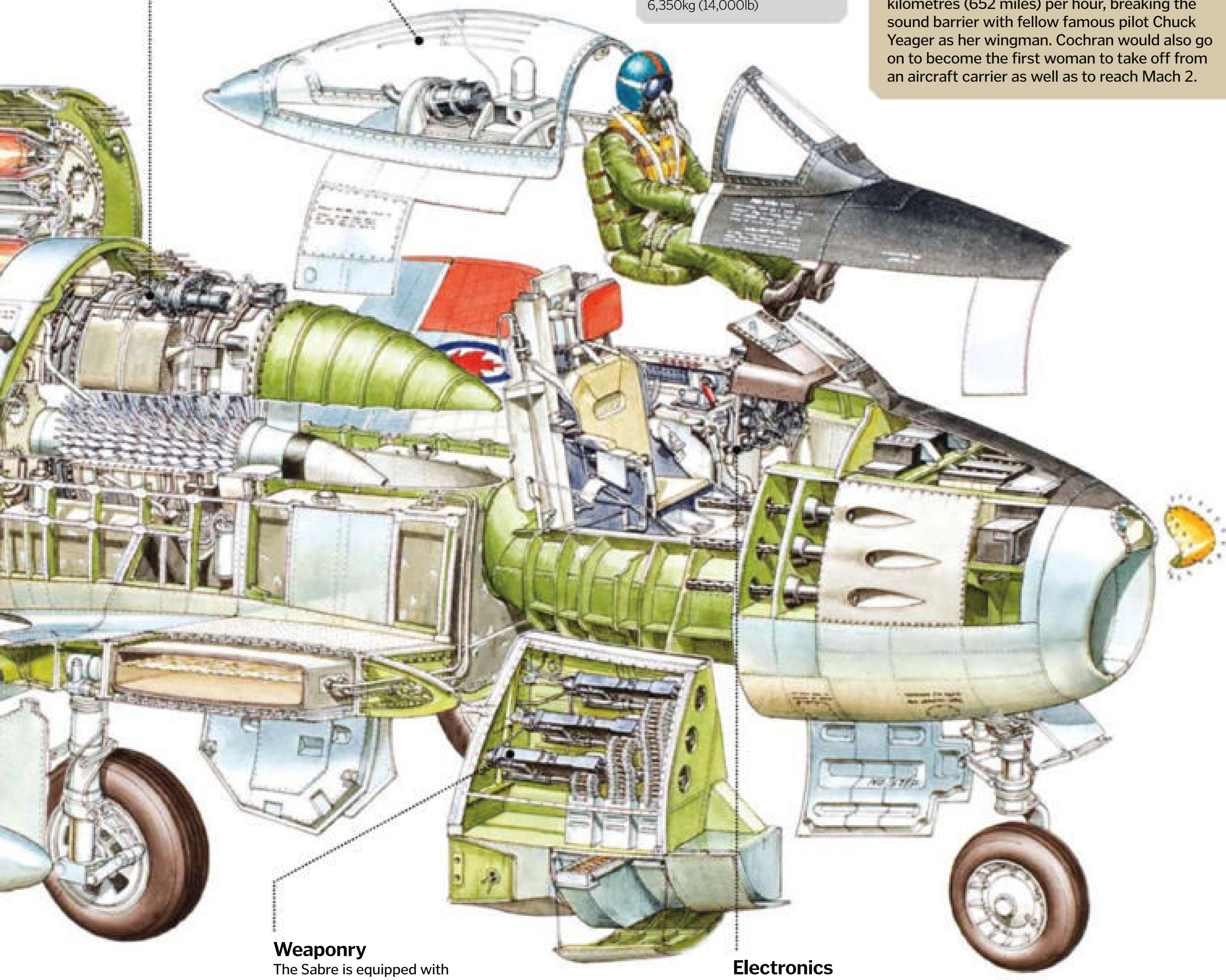
Max altitude: 1,371m (45,000ft)

Combat weight: 6,350kg (14,000lb)

Who was high flyer Jacqueline Cochran?

Born in 1906, Jacqueline Cochran was a pioneering American aviator and one of the most gifted pilots of her generation. This skill in the air eventually led her to become the first woman in the world to officially break the sound barrier – an amazing feat which she performed in a custom-built, one-off F-86 Sabre.

The record was broken on 18 May 1953 at Rogers Dry Lake in California. In her F-86, Cochran racked up an average speed of 1,050 kilometres (652 miles) per hour, breaking the sound barrier with fellow famous pilot Chuck Yeager as her wingman. Cochran would also go on to become the first woman to take off from an aircraft carrier as well as to reach Mach 2.



Weaponry
The Sabre is equipped with six .50-caliber (12.7mm) M2 Browning machine guns and 16 127mm (5in) HVAR rockets, as well as a variety of freefall bombs and unguided missiles.

Electronics
An A-1CM gun sight in partnership with an AN/APG-30 radar system makes the F-86E one of the most technologically advanced jets of its time. The radar can quickly work out the range to potential targets.

BRAIN DUMP

Because enquiring minds want to know…

Ask your questions

Send us your queries using one of the methods opposite and we'll get them answered

MEET THE EXPERTS

Who's answering your questions this month?

Luis Villazon

Luis has a degree in Zoology from Oxford University and another in Real-time Computing. He's been writing about science and tech since before the web. His science-fiction novel *A Jar Of Wasps* is published by Anarchy Books.

Giles Sparrow

Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in publishing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries*.

Alexandra Cheung

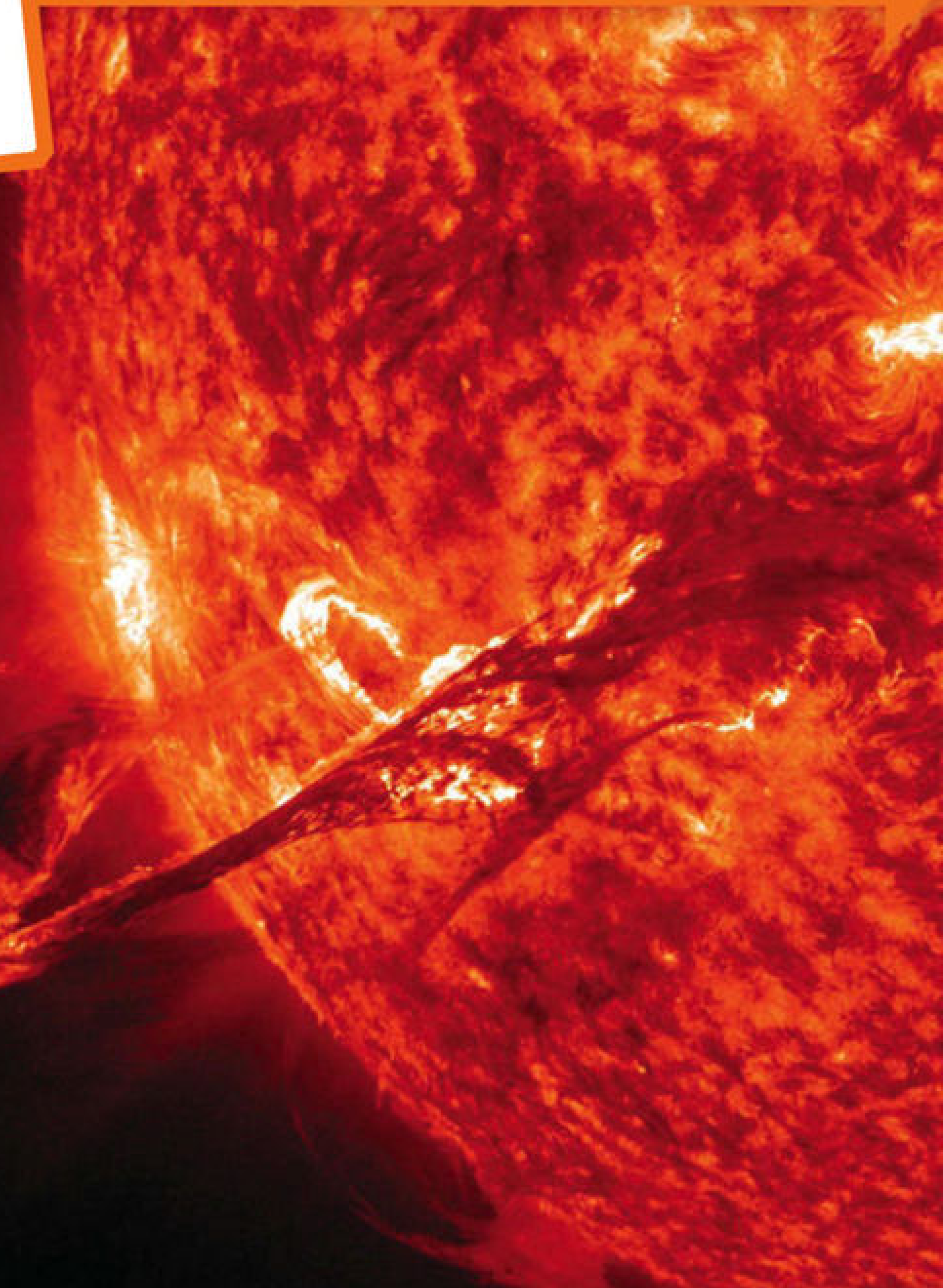
With degrees from the University of Nottingham and Imperial College, Alex has worked for several scientific organisations including London's Science Museum, CERN and the Institute of Physics. She lives in Ho Chi Minh City, Vietnam.

Tom Harris

Hailing from North Carolina, Tom is an experienced science writer who, over the years, has produced hundreds of articles which demystify complex subjects for both magazines and general knowledge books. In his spare time he's a keen dog rescue volunteer.

Dave Roos

A freelance writer based in the USA, Dave has researched and written about every conceivable topic, from the history of baseball to the expansion of the universe. Among his many qualities are an insatiable curiosity and a passion for science.



Could a solar flare cause mayhem for electronics here on Earth today?

Ben Pratley

■ Definitely. When a coronal mass ejection (CME) from a solar flare reaches Earth, the fluctuating magnetic fields induce electrical currents in any long conductor. In oil and gas pipelines this can cause sparks that trigger fires and explosions at terminals and in power lines the surge can overload transformers. In 1989 a powerful flare knocked out the electricity grid for 6 million people in Québec, Canada. The largest-ever recorded flare in 1859 gave telegraph operators electric shocks from the telegraph wires. If a similar flare occurred today – with our much more sensitive equipment – the damage could easily run to billions. **LV**

Generally CMEs leave the Sun at a speed of 650km (400mi) per second

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Are sultanas, currants and raisins the same?

Violet

The term 'raisin' covers all types of dried grapes, so sultanas and currants are technically raisins. Most of the 'raisins' available in shops are dark-coloured ones made from the Muscatel variety of white grape. Sultanas are smaller and lighter than the average raisin, originating from sultana (also called Thompson seedless) grapes – although in some countries (like the USA) the name sultana is used to describe any raisin treated to re-create the sultana's golden colour and juicy texture. Finally, currants are dried seedless red grapes of the Black Corinth variety. One of the oldest types of raisin, they owe their name to the Ancient Greek city of Corinth, a major exporter of currants to Europe in the 15th century. **AC**

Do appliances use more power on standby?

Stuart Flynn

The average 81-centimetre (32-inch) TV uses 123 watts when on – rising to 235 watts for a 107-centimetre (42-inch) screen – but even when switched 'off' with the remote, it's still using five watts. An Xbox 360 uses about 170 watts when on and just 2.2 watts on standby (1.2 per cent). However some set-top boxes can use almost as much power on standby as normal running. A 2013 study at the Lawrence Berkeley Laboratory, CA, found that satellite decoders used 16.15 watts on average when they were on and 15.66 watts when they were off at the remote – that's 97 per cent of full power.

Even just five watts per appliance can quickly add up, of course. The average UK household spends £50-90 annually on electricity to power devices that are supposed to be off. **LV**

How many types of Greek temple are there?

Andrew Cox

There are three different types of Greek temples representing the three 'orders' of Ancient Greek architecture: Doric, Ionic and Corinthian. All three orders employ similar architectural elements, most notably columns. Doric – the oldest order – uses relatively short, thick columns, while the columns of later orders are longer and more slender with concave vertical grooves called fluting. Resting atop each column is a 'capital' of varying complexity. The Doric capital is simple and understated, while the Ionic version has swirling volutes that resemble ram's horns, and the Corinthian order boasts ornate leaves and scrolls. Ancient Greek architecture is founded upon principles of order and symmetry, and the Greek temples of the Classical period – roughly 500-300 BCE – provide some of its finest examples. Famous Greek temples like the Parthenon (Doric) and the Temple of Athena Nike (Ionic) – both in Athens – have inspired architects from the Renaissance right through to modern times. **DR**

The world-famous Doric Parthenon was built in the fifth century BCE on the Acropolis in Athens, Greece

Secretary birds are related to raptors, but while they can fly, they spend much of their time on the ground

How did the secretary bird get its name?

Matthew Warner

The origins of the secretary bird's name are much debated. One theory is that the feathers jutting out behind the bird's head reminded 19th-century Europeans of the quill pens that secretaries tucked behind their ears, while its grey and black body was reminiscent of their tailcoats. A more recent theory is that the name derives from the Arabic 'saqr-et-tair', or 'hunter bird'. The secretary bird is a large bird of prey found in grasslands and savannah across Sub-Saharan Africa. It is one of only two birds of prey preferring to hunt on foot (the other being the caracara). At 1.2 metres (four feet) tall, its height allows it to spot insects, lizards, snakes and rats in the tall grass. **AC**

Which was the first civilisation to drink tea? Find out on page 84

BRAIN DUMP

Because enquiring minds want to know...

What is snow blindness?
Find out on page 85

Want answers?

Send us your questions using one of the methods opposite and we'll get them answered

Does shooting a car's fuel tank make it explode?

Danny B

■ Essentially this is nothing more than a movie myth. An explosion requires three things: fuel and oxygen mixed in the correct proportions, and a heat source. A petrol tank, unless it is very nearly empty, doesn't have enough air in it for an explosive mixture and bullets don't always create sparks when they strike metal. **LV**

Which culture began the practice of drinking tea?

Eleanor Fields

■ According to legend, Chinese emperor Shennong enjoyed the first cuppa, way back in 2737 BCE. Allegedly, while the emperor was sitting in his garden, leaves from his Camellia sinensis plant drifted into drinking water that he was boiling. Shennong loved the result, and tea was born.

There's no proof that the above scenario actually happened, but the evidence does point to tea originating in China's Yunnan province, sometime before 1000 BCE. Historical references indicate that it was originally considered a medicinal drink. Only during the Tang Dynasty (beginning 618 CE), did it become thought of as a tasty treat.

Dutch traders brought tea to Europe around 1606, and it steadily gained popularity. It hit big in Britain after 1662, when King Charles II married the Portuguese princess and avid tea fan, Catherine of Braganza. **TH**

If I allow cookies on my PC, will it be hacked?

Kimberly

■ No, they don't make it easier for you to be hacked. Cookies are just small text files used as temporary storage on your computer. Websites use them to remember who you are – just like a store card for a shop. Cookies don't contain your credit card number or your computer's password, and they are only ever sent back to the website that created them in the first place. Turning off cookies just means that websites won't remember that you are already logged in and they might keep showing you the same advert, because they won't know that you've already seen it. **LV**

If magnets can push away from each other, why can't we make hover cars?

The Shanghai Maglev Train started operating in 2003

Harvey

■ Wouldn't that be an amazing sight – thousands of magnetic hover cars cruising silently along a futuristic highway? In fact, this exact type of technology already exists. It's called magnetic levitation (maglev for short), and it's been developed since the Seventies to power high-speed trains in Europe and Asia. With maglev trains, both the train car and the rails exert electromagnetic fields that repel each other. The electromagnets double as levitation and propulsion systems, pushing frictionless trains to speeds upwards of 580 kilometres (360 miles) per hour. Maglev cars, although technologically feasible, would require a road surface embedded with electromagnetic tracks at massive expense. **DR**

In solar winds, what are Alfvén waves?

Dan James

Alfvén waves are a special type of wave that are found in the Sun's upper atmosphere and extend out into the solar wind that blows out from the star across the Solar System. They are created by electrically charged particles called ions 'rippling' at right angles to a magnetic field, and their existence was first predicted by Swedish physicist Hannes Alfvén in 1942.

Satellites found the first traces of natural Alfvén waves in interplanetary space shortly after the beginning of the Space Age (in the Sixties), but their existence in the Sun's outer atmosphere (corona), was only confirmed in 2011. Many astronomers believe they could be responsible for transferring energy and heating up the corona, explaining why it reaches scorching temperatures of up to 2 million degrees Celsius (3.6 million degrees Fahrenheit) – much hotter than the Sun's visible surface. **GS**

Alfvén waves kickstarted the field of magnetohydrodynamics, which would earn Alfvén the 1970 Nobel Prize in Physics

What causes snow blindness?

Adam Weaver

The medical term for this condition is photokeratitis – literally sunburn of your cornea. At high altitude, light reflected off snow contains dangerous levels of UV radiation. Like sunburn, the effects are delayed. Climbers report painful burning, blurred vision and a sandy sensation on the eye starting 6-12 hours after exposure. It turns out that the best protection against snow blindness is a good pair of UVB-rated sunglasses with side shields. The best cure is to patch the eyes and let them heal themselves, which can happen as quickly as 24 hours. Interestingly hand-carved Inuit snow goggles are equally as effective as a pricey pair of Ray-Bans. **DR**

Does a compass work underground?

Jamie Dobie

The computerised compass app you have on your phone probably won't work because it relies on radio signals that are easily blocked by rock or water, but for a traditional compass with a wobbly needle, it just depends on how far underground. This kind of compass works because its magnetised needle lines up with the magnetic field that runs between Earth's north and south poles, and that field is just as powerful if you go down a mineshaft or into the depths of the ocean. But the field is created by swirling molten iron in Earth's core, and if you could drill that far down, you'd find your magnetic needle going haywire. **GS**

If there is absolute zero, is there absolute hot?

William Gibcus

The concept of absolute zero is well understood, but 'absolute hot' is more enigmatic. Heat is a form of energy associated with the motion of the atoms that make up matter. The colder it gets, the less particles move and vibrate, winding down to a virtual standstill at absolute zero (0 Kelvin/-273 degrees Celsius/-460 degrees Fahrenheit). At the other end of the scale, conventional physics sets the theoretical maximum temperature at 1.4×10^{32} Kelvin: the Planck temperature, believed to have last occurred a fraction of a second after the Big Bang. Above this, particles would have so much energy that our current theories could no longer explain their behaviour, meaning that at this time no hotter temperature can be conceived of. But one day a theory of quantum gravitation could allow for even hotter temperatures. **AC**

Current physics only allows for temperatures to reach 1.4×10^{32}K

What are binary stars? Find out on page 87

BRAIN DUMP

Because enquiring minds want to know...

How far can a sniper shoot?
Find out on page 87

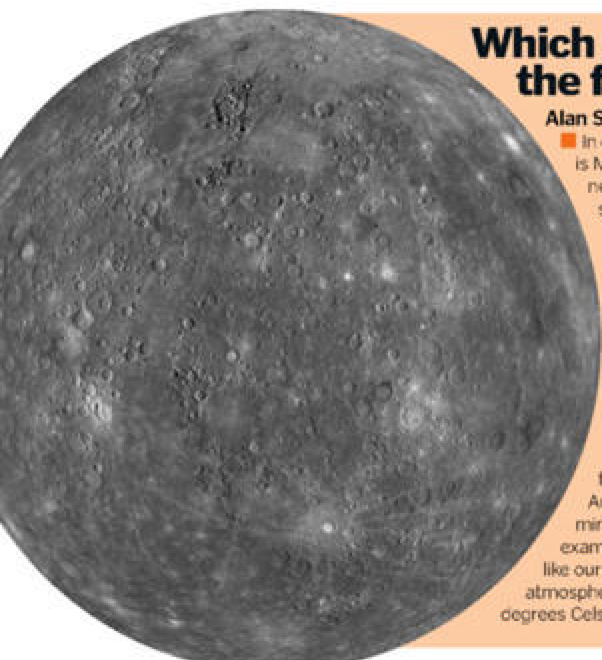
Want answers?
Send us your questions using one of the methods opposite and we'll get them answered

Pinnipeds live all over the planet from the balmy Californian coast to the frozen Arctic, like this baby harp seal

From what species did seals evolve?

Suzanne J Sale

■ Along with sealions and walruses, seals belong to a group called pinnipeds, which evolved from land animals. Researchers pinned down concrete evidence of this transition in 2007 with the discovery of Puijila darwini. Alive 20-24 million years ago, this amphibious freshwater carnivore had the muscular legs characteristic of a land creature but the webbed feet, streamlined body and tail of an aquatic animal. The theory goes that P darwini lived in once temperate Arctic lakes and rivers before gradually switching to an ocean lifestyle as these lakes began to freeze over. **AC**



Which planet moves the fastest?

Alan Stone

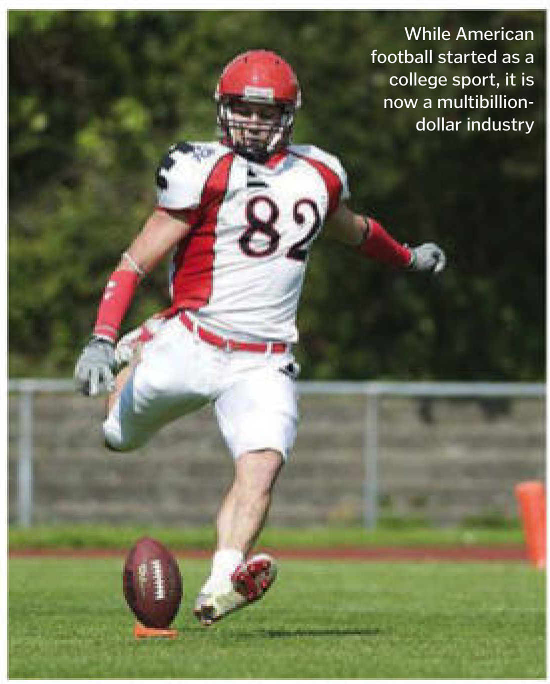
■ In our Solar System, the fastest mover is Mercury. It zips along its orbit at nearly 50 kilometres (31 miles) per second, and completes an orbit of the Sun every 88 days – that's why early stargazers named it after the fleet-footed messenger of the gods. Outside the Solar System, however, there are planets that would leave Mercury in their dust. New ones are being found all the time, but the most impressive example so far is probably WASP-12b, discovered in 2008. This world, some 871 light years from Earth in the constellation of Auriga, takes just 26 hours and 12 minutes to orbit its star. It's a famous example of a 'hot Jupiter' – a gas giant like our own Jupiter, but with an atmosphere that's heated to a scalding 2,200 degrees Celsius (4,000 degrees Fahrenheit). **GS**

Did American football derive from rugby?

Sam

■ Yes. In the 1860s, 'football' referred to all sorts of variations on a theme: two teams moving a ball to the opposing goal, on foot rather than on horseback. Different cities and schools adapted the idea with their own ever-evolving rules.

In the 1870s, England's Rugby School variation took hold with US players, largely thanks to two prominent matches between Harvard and Canada's rugby-loving McGill University. At Yale, a student named Walter Camp led the charge in re-imagining rugby with new additions like the quarterback, line of scrimmage, plus the down-and-distance system. Over time, in American universities, this new form of football became the standard. **TH**

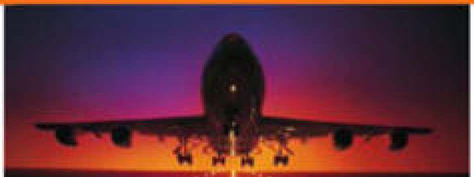


While American football started as a college sport, it is now a multibillion-dollar industry

Why do tongue-twisters trip us up?

Michael Blatner

■ A recent study of three epilepsy patients has shed new light on this linguistic phenomenon. Electrodes implanted in the subjects' brains in preparation for surgery allowed a team from the University of California, San Francisco, to record neural activity from the brain surface. The scans showed that sites in a region called the ventral sensorimotor cortex (vSMC) control different parts of the vocal tract (tongue, lips, etc) to form each syllable. Stringing syllables together appears to require co-ordinating complex sequences of activity across vSMC sites, timed down to tens of milliseconds. Sounds that require similar vocal tract movements, such as 'Sss' and 'Shh', are especially tricky as their representations in the brain overlap. Tongue-twisters are likely tricky because they require a rapid sequence of overlapping neural patterns that simply overwhelms the brain. **TH**



Can EM pulses knock planes out the sky?

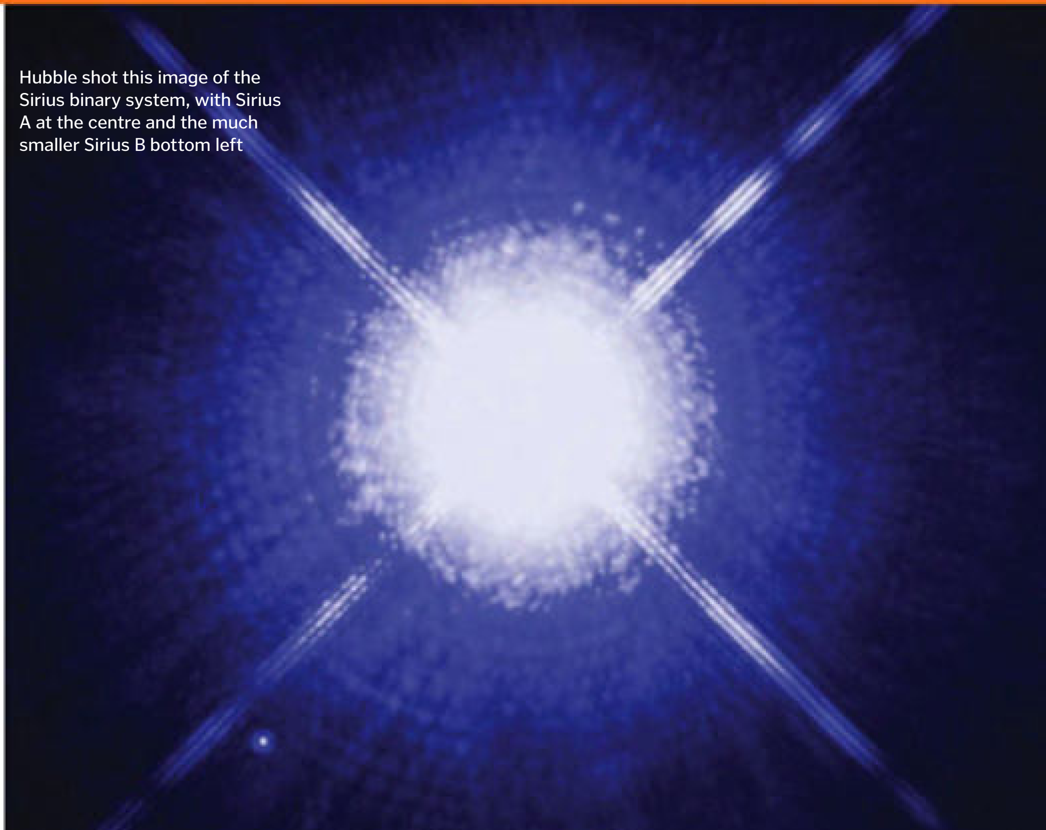
Robin Gunn

If an aeroplane were caught in an EMP strike, it could destroy all its guidance, navigation and communication systems making it virtually impossible to fly. An electromagnetic pulse (EMP) is a burst of high-energy photons. A flash of light is also a burst of photons, but visible light photons have much lower frequency and energy than the photons found in an EMP. When you detonate a nuclear bomb in the atmosphere, the high-energy gamma rays ionise the air molecules and essentially cause a massive EMP. The USA has developed specialised EMP weapons designed to create a more focused pulse over a smaller area. **LV**

Could a sniper hit a target a mile away?

Joey Bartlett

Absolutely. In fact, the current combat record distance is 2.8 kilometres (1.7 miles). The actual record-holder is a mystery, but we know it was one of two Australian snipers who fired simultaneously. One of them hit their human target. At that distance, the snipers were out of visible range to the naked eye and far enough away that the target couldn't hear the shot. The bullet was in the air for six seconds. The Australian snipers used Barrett Model 82A1 rifles, which have a listed effective range of 1.8 kilometres (1.1 miles). To hit a target at that range, however, a sniper has to make a series of fine adjustments to account for the effects of gravity, wind, temperature and even humidity. The previous record-holder was British Corporal Craig Harrison, who managed to hit two targets in quick succession from 2.4 kilometres (1.5 miles) away. **TH**



Hubble shot this image of the Sirius binary system, with Sirius A at the centre and the much smaller Sirius B bottom left

What are binary stars?

Sandra Hutchings

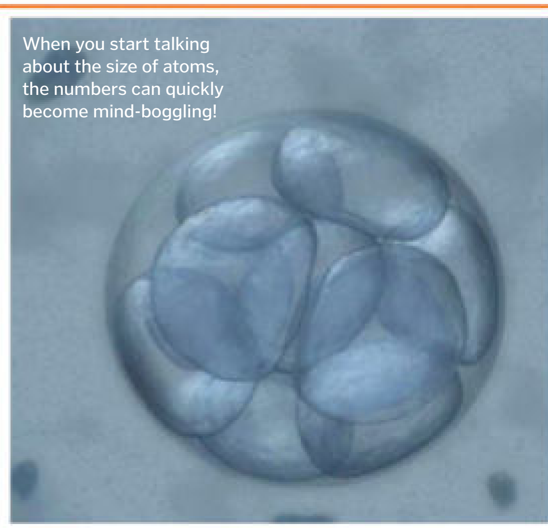
A binary star system is a pair of stars that orbit each other. They are very widespread, and in fact the majority of stars in the Milky Way are members of binary or multiple systems (with three or more stars): loners like our Sun are in the minority. The distance between stars in a binary system can vary hugely – some take millions of years to orbit each other, while others do it in just a few days. Astronomers find binaries very useful – the stars in these systems have spent their entire lives together, and were born at the same time from a shared cloud of gas/dust. What's more, the way in which each star orbits can give away its relative mass. So it's easy to compare how factors such as the mass of each star have affected their evolution and appearance as we see them today. **GS**

How many atoms does an object need for the human eye to see it?

Eric Bowerbank

Wow, that's a tough one! The best we can do is to calculate a very rough approximation. Humans can see objects as small as 100 micrometres (0.01 millimetres/0.0004 inches) with the naked eye. A human egg cell, for example, is 130 micrometres in diameter, and its volume (assuming it's a perfect sphere) is 1.15 million cubic micrometres. One of the most common molecules in the human body is glucose ($C_6H_{12}O_6$), containing 24 atoms. Let's pretend, for the purpose of this example, that a human egg is entirely composed of glucose molecules. The diameter of a glucose molecule is roughly one nanometre, and there are 1,000 nanometres in a micrometre.

So, for example, if you know that there are 1.15 billion glucose molecules in a human egg cell (1.15 million cubic micrometres x 1,000 nanometres), and each molecule contains 24 atoms, that gives us 27.6 billion atoms in a single human egg cell, one of the smallest objects that can be seen by the naked eye – at least theoretically! **DR**



When you start talking about the size of atoms, the numbers can quickly become mind-boggling!

THE KNOWLEDGE

FOR CONNOISSEURS OF KIT AND SAVANTS OF STUFF

Dali Epicon 2 speakers

Can this high-end audio device live up to its huge price tag? We find out

Price: £3,750/$6,495
Get it from: www.dali-speakers.com

There's a maxim lingering in the back of our mind, which goes something like, 'If it's heavy, then it's expensive'. That would probably be followed by an angry grown-up telling us to "Put it down!". We can barely pick up Dali's Epicon 2 speakers in their flight case though – they're *that* pricey – and they're still pretty hefty out of the box. But boy do they look good.

These speakers have a rock-solid build with a svelte, curved cabinet and glossy walnut finish that puts us in mind of a winter lodge: they're available in black and red too, if natural wood's not your thing. So we're impressed before we've even rigged them up to our sound system (which respectably clocks in at around half the price of the Epicon 2) and tentatively thrown a few acoustically wide-ranging morsels at it.

Sigur Rós's euphoric ambience seems like a good start, followed by Royksöpp's *Alpha Male*. The delivery from the Epicon 2's 16.5-centimetre (6.5-inch) mid and bass driver is both warm and enthusiastic, with a tweeter that helps the entire sound experience stretch to acoustic details that get the spine tingling. Lastly, we throw on something a little more heavy and pacey (read: Foo Fighters), then crank up the volume to hear the Epicon 2 explode into life.

In the wake of one of the most pleasing home audio experiences we've ever had, we faced a reality-check with that jaw-dropping price. It puts Dali's Epicon 2 speakers firmly out of the reach of the average high-street shopper and into audiophile territory – especially as you'll need an audio setup to do the speakers justice. But are they worth every penny? Absolutely.

Verdict:

The statistics...

Max sound pressure level: 108dB
High-frequency driver: 1 x 29mm (1.1in)
Low-frequency driver: 1 x 165mm (6.5in)
Weight (combined): 10.3kg (22.7lb)
Frequency range: 47-30,000Hz
Connection input: Bi-amping
Dimensions: 386 x 214 x 366mm (15.2 x 8.4 x 14.4in)

APPS OF THE MONTH

Brought to you by **Apps Magazine**, your essential guide to the best iPhone and iPad apps available on the Apple App Store

iPad: America's Presidents

Price: £4.99/$6.99
Developer: Smithsonian Institution
Version: 1.0
Size: 696MB
Rated: 4+

Do you know which president owned a pet raccoon, or which posed for a portrait in a cape? The answers to these questions and more can be found in America's Presidents. As the first-ever virtual tour of the Smithsonian's National Portrait Gallery, the app offers an interactive journey through some of the most iconic figures in US history. From Washington to Obama, you can view the portraits on a timeline or individually, double-tapping to see them up close. Each portrait comes with a detailed description of their term, along with famous quotes.

Verdict:

iPhone: CARROT: The Todo List with a Personality

Price: £0.69/$0.99
Developer: Brian Mueller
Version: 2.0
Size: 7.0MB **Rated:** 9+

A novel take on a to-do list app, CARROT talks to you and awards you points for every job you finish, which translates into levels and boosts CARROT's mood. But be warned, leave too long between tasks and CARROT will get angry!

Verdict:


CELESTRON
Advanced Series GT
Computerised Equatorial mounted telescopes
NexStar SLT Series
Computerised beginner telescopes with SkyAlign
NexStar SE series
Fully computerised telescopes
CPC and CPC Deluxe Series
Fully computerised GPS assisted SCT and HD telescopes
AstroMaster Series
Premium starter telescopes
Popular accessories
SkyQ Link WiFi adapter module
NexStar carry cases
NexImage 5 Solar System Imager (5 MP)
NightScape 8.3MP and 10.7MP CCD cameras
PowerTank 7ah and 17ah (reduced prices)
X-Cel LX 60° 6 element parfocal eyepieces
Luminos 82° WA parfocal eyepieces
Baader Classic Q-Eyepiece Kit
Baader MK III Zoom and Hyperion 2.25x Kit
Baader Zero-Tolerance Protective EOS T-ring
STOCKIST CELESTRON SUPERCENTRES
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F1 Telescopes Sittingbourne 01795 432702
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CONS
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CONS
No included microscope

Genetics & DNA

Price: £22.99/$34.99
Get it from: www.scienceshop.com
We got very excited by this kit at first, with the promise of isolating the DNA of a tomato at our fingertips. But inside there seems to be an awful lot of bits of paper and plastic – for the inheritance learning game and model of a double helix, you see. It occurred to us shortly after playing around with some denatured alcohol (not provided) and a tomato among other things that, even if we could extract DNA from fruit and veg, we'd need an electron microscope and a well-equipped biology lab to see the funky spirals of a DNA strand that we secretly hoped to see. Pieces of separated tomato floating in a test tube doesn't quite live up to those expectations. However, the imagination of some relatively jaded journalists pales in comparison to the generation this kit is intended for. And there's a lot to entertain young minds here. The DNA extraction experiments, model DNA kit and trait games aside, there's a bacteria culture kit and Petri dish to grow your own colony in… whatever that may be. Plus, you're equipped with goggles, pipettes and other lab paraphernalia to give a sense of being a proper scientist. There's certainly plenty to keep a budding geneticist occupied for a few hours.

Verdict:

Chem C1000

Price: £44.99/$89.99
Get it from: www.scienceshop.com
Of the three experiment kits we were looking forward to, Chem C1000 was the one we wanted to play with the most. There's nothing like the bubbles, bangs, smells and colours of a fantasy chemistry lab to pique the curiosity. Or a little bit of danger, for that matter. This is an over-the-counter chemistry set, however, and not one from the 19th century either so, expectations firmly managed, we eagerly opened the box and scrutinised a handful of labelled vials. Chem C1000 boasts 125 different experiments and tests involving some very familiar chemicals from our school science classes – litmus testing and azure copper sulphate powder among them. Like Physics Workshop, an 80-page manual leads you by the hand through each experiment, challenging you to replicate the conditions using the chemicals provided plus a few other household products, then showing you the theory behind it. We never thought we'd be splitting water into hydrogen and oxygen or creating a battery from a chemical solution, but were pleasantly surprised with what we could do with a few 'safe' chemicals and utensils. Unlike Physics Workshop, the life of this kit might be held back by the chemical supplies, but we'd opt for Chem C1000 every time.

Verdict:

Physics Workshop

Price: £39.99/$54.95
Get it from: www.scienceshop.com
We remember this from our own childhood, or something like it anyway. At a glance, this might look like a Meccano kit – and it is, kind of. Albeit a rather versatile Meccano kit with some real science teeth to it. A series of cogs, poles, bricks, plates, chains and other plastic bits and bobs, plus a wind-up motor, all come together in different guises to help a budding physics student answer questions like: at what angle should you throw a ball to obtain the maximum distance? And why is it easier to balance on a bicycle that's moving than one that's stationary? The answers to all the questions come via an especially practical and accessible Physics Workshop experiment manual. This surprisingly thick guidebook is brilliant at taking you through the theory of the dozens of experiments it tasks you with, in a light and entertaining manner. You read the problem, build the experiment, see the physical solution in action and then learn the theory behind it. The actual model-building instructions are nowhere near as detailed as those in a Meccano set however, leaving a lot up to three or four step-by-step images to explain how to construct the more sophisticated experiments, which for some may not be enough.

Verdict:

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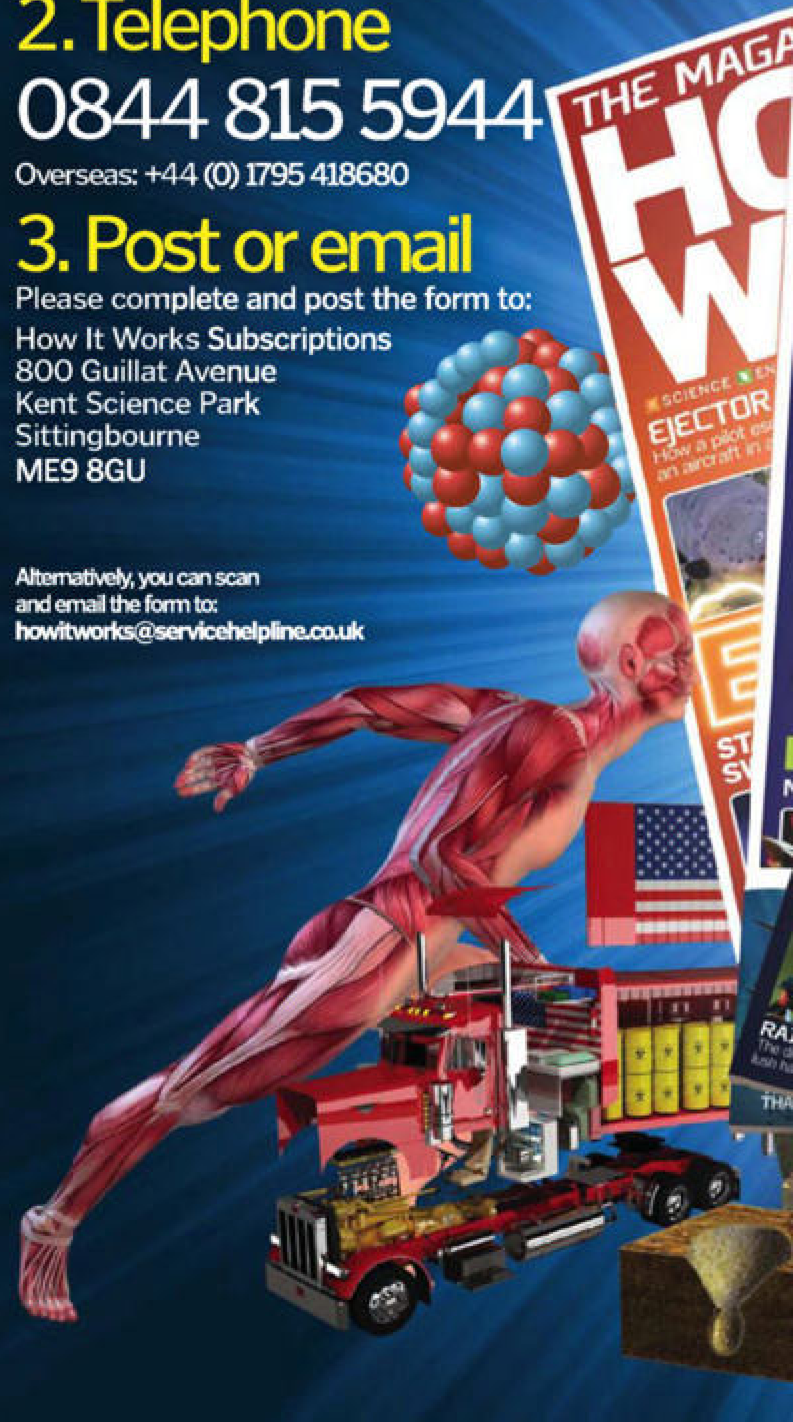

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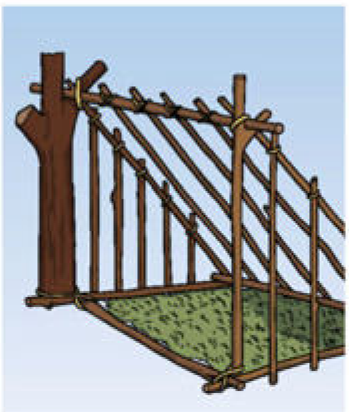


1 Assess the terrain

The type of shelter you build will depend on local materials, conditions and length of stay. For short-term stops, opt for a bough shelter – where a small tree is cut at the trunk and allowed to fall so its canopy can act as a makeshift roof. For longer stays, sapling, sheet and tepee shelters are better. Even if you're intending to build a long-stay shelter, it's a good idea to create a short-term option in case the weather suddenly turns bad.

2 Sapling shelter

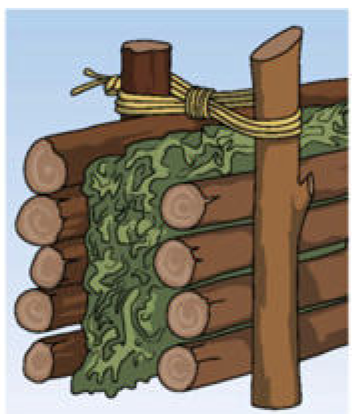
Not surprisingly these are suited to areas of young woodland. Find two rows of saplings, clear the ground between them and lash their tops together. This will form a crude tunnel frame over which sheeting can be laid. The material should be secured at either side of the frame with rocks or logs. If no sheeting is available, try weaving together the saplings' branches and then stuff any gaps with ferns, leaves and/or turf.

3 Sheet shelter

If saplings aren't available, another option is the sheet shelter. This requires canvas/sheeting, but it can be assembled in several ways. For instance, the triangular sheet shelter is made by strapping two large branches together in an inverted 'V', sharpening the ends, driving them into the earth and using the strapped end's nook to wedge a supporting crossbeam branch. This crossbeam can be used to hang the canvas off.

4 Tepee shelter

If more than one person needs to be accommodated, the tepee shelter is more practical. This is created by strapping three or more large branches together at the tips to make a cone-shaped frame. The branches should be crossed and tied on the ground, prior to lifting. Now any sheeting can be hung around the frame; if no artificial material is available, you could also use bark sheets, animal hides or leafy branches.



5 The final frontier

Regardless of which shelter type you plump for, you'll benefit from an external wall. These can be easily constructed by piling sticks between upright branches/logs driven into the ground, before applying caulking (ie sealing) materials such as mud and foliage. The wall should ideally be built in front of the shelter's opening. This helps keep the bivouac warm and stops the wind from extinguishing your all-important fire too.

In summary…

Many different kinds of bivouac shelter can be created using a mix of natural and synthetic, or solely natural, materials. Importantly, the type of shelter built should be reflective of your environment and duration in the area. Quick shelters such as bough and natural hollow varieties are ideal for a short stay, as they're quick to make. If a more permanent shelter is needed, consider tepee or lean-to types. The secret is to use the local terrain and plant life to your advantage.

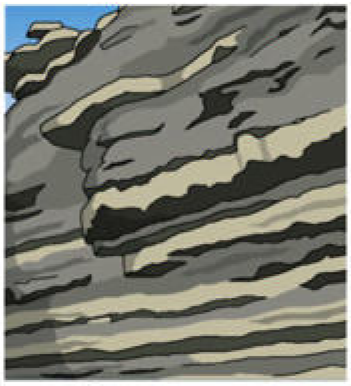
NEXT ISSUE
- Hang a picture
- Make a rope bridge

Hunt for fossils

Go forth and discover prehistoric treasures with our amateur palaeontology guide

1 Rock on

It may sound fairly obvious, but to find fossils you need to be looking in the right place! Fossils are generally unearthed in sedimentary rocks like sandstone, limestone and shale, with the majority exposed in areas that experience frequent erosion, such as cliffs along the coast and riverbanks. Sedimentary rocks are easily identified by their multilayer composition.



2 Train your eyes

There's no denying the fact that finding fossils involves a good pinch of luck, but there are things you can do to maximise your chances of success. The best of these is to actually have a mental picture of what you are looking for prior to heading out. This will make spotting fossil patterns amid a complex sea of rock and shale – such as those of snail-like ammonites – far easier.

3 Tool up

Of course, even if you do find a fossil, it will more than likely be encased within a rock. If you intend to collect it – and you should first make sure that no restrictions are in place in the area – then you need some specialised tools. Fossil picks, chisels and hammers are all key kit, while specimen boxes and a trusty magnifying glass can also come in handy.

In summary...

Anyone can find fossils so long as you take a methodical and realistic approach. Visualising the fossil is a great starting point, while identifying fossil-rich regions prior to your search will dramatically improve success rates. Chisels and hammers might not help you find the fossil, but they will help to free it from rocks without damage.

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TEST YOUR KNOWLEDGE

ENJOYED THIS ISSUE? WELL, WHY NOT TEST YOUR WELL-FED MIND WITH THIS QUICK QUIZ BASED ON THIS MONTH'S CONTENT?

1. What was the maximum submerged speed of the VII-C U-boat (mph)?
2. In which century is the Celtic civilisation thought to have reached its peak?
3. How many confirmed moons does Saturn have?
4. In which year did Yuri Gagarin become the first human to travel into space?
5. What size sensor does the Nikon D600 DSLR camera have?
6. How many primary data centres does Google have around the world?
7. At least how many millimetres of rain does a rainforest get per year?
8. How many trees were knocked flat by the 1908 Tunguska event?
9. Allegedly when did Emperor Shennong drink his first cup of tea?
10. When were Alfvén waves first hypothesised by Hannes Alfvén?

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at **www.howitworksdaily.com** and one lucky reader will win a model of the Vostok rocket which took the first man into space – good luck!

AIRFIX

ISSUE 45 ANSWERS

1. Xinting **2.** 90kg **3.** 160,000LY **4.** Lead-acid **5.** 1,000
6. 1,100m/s **7.** Jupiter **8.** Confucius **9.** Andromeda **10.** 50

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We enjoy reading your letters every month. So keep us entertained by sending in your questions and views on what you like or don't like about the mag.

FANTASTIC PRIZE FOR LETTER OF THE MONTH!

WOWee ONE

WIN A WOWEE ONE PORTABLE SPEAKER

This issue's top letter wins a WOWee One Classic portable speaker. This turns any surface into a bass amplifier using gel technology, and is compatible with all iDevices and other mobile gadgets.

Power stations convert mechanical energy into AC electric current

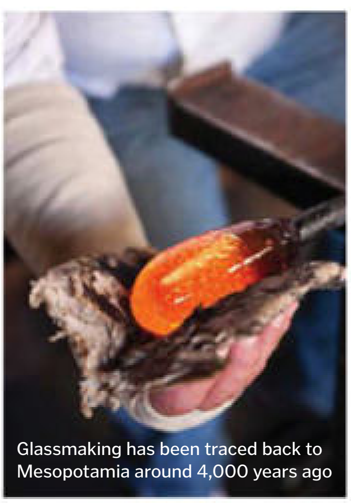
Letter of the Month

A look at current affairs

Hi Alex,

I enjoyed reading your article on the production of electricity (issue 44) and how negatively charged electrons can be freed by passing a magnetic field over a coil of copper conductor. What puzzles me though is that there must be a finite number of electrons, so that after decades of coils of copper whizzing across a magnetic field in, say, a generating station, where does the flow of electrons keep coming from? Why does the coil not become exhausted?
Puzzled,
Ray Potter

Although the movement of electrons is what creates an electric current, this current can only exist in a circuit (ie a closed loop) from which electrons never actually leave. In a DC circuit, electrons simply move around the circuit: as electrons leave one section they're instantly replaced by others behind them. Even if this current is powering an appliance this doesn't 'use up' electrons, so they're never exhausted. In the case of a power station, the current generated is usually AC. With AC, the flow of electrons periodically alters direction, so electrons move back and forth, effectively going nowhere. (Alex Cheung)



Glassmaking has been traced back to Mesopotamia around 4,000 years ago

A bit unclear about glass

Dear How It Works,

I have often wondered how glass is made, so could you help me? I have always been intrigued where glass comes from – and stained glass in particular.
Stephen Jackson

Hi Stephen,
Glass is made by heating silica in the presence of catalysts like potash or soda to lower the temperature required to melt it, then substances like lime are added to restabilise it. There are a number of techniques used for different types of glass, but this core process remains the same. To colour the glass, chemicals are added to the liquid mix. Adding manganese yields a purple shade, for example, while tiny quantities of gold generates a vibrant ruby red.

A sight to behold

Hello HIW,

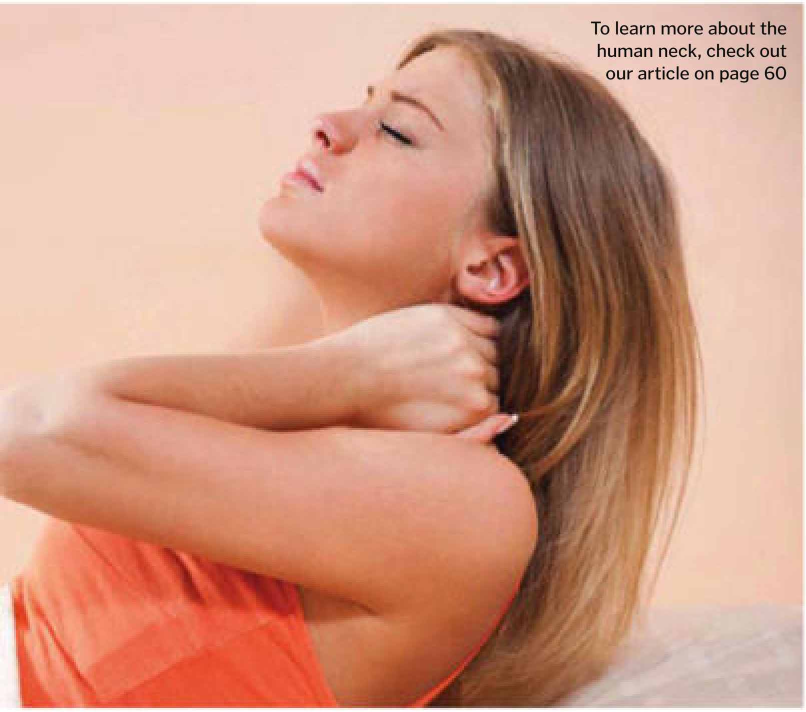
I recently purchased a Mk 5A RAF gun sight from a junk shop for £15: it is from a crashed Meteor (circa 1956) – can you tell me how it works?
John Burton

Reflector sights were invented in 1900 and were widely used on fighter aircraft in World War II. They create an 'infinity' image of the object at the focus of the lens with a sight that includes the field of view by bouncing the image off a mirror or clear curved glass. It means the reticle will always remain on the target, even if the viewer's head is moving. We like the idea of this being recovered from a 'crashed Meteor', John, even if you did mean the British Gloster Meteor jet fighter as opposed to an extraterrestrial rock from space!

Getting it in the neck

Hi,

We have a question for How It Works. We would love to know: what is a stiff neck? We understand why it happens (sleeping with a fan blowing on your neck, for instance), but we want to know what actually happens to the muscle and why you can't just rub/massage it out to get rid of it. What happens to the muscle as it



To learn more about the human neck, check out our article on page 60

“Researchers were able to create the invisibility cloak using an artificial nano-structured crystal from silicon and laser beams”

gets better? Is it relaxing? Is it reshaping? We’re really looking forward to your answer. Thank you!
Jeff and Gina Gillard

Neck pain can be caused by a huge range of factors – both congenital and environmental – but the most common causes are the muscle being strained, as a result of poor posture, injury or even (as you say) sitting in a draught. Outside of injury or illness, the muscles in the neck are simply too tense, contracting to a point where the neck is made very inflexible. A good massage or heat treatment in the right place can help the muscles to relax and lengthen again, although some time relaxing in a good posture can do the same job.

Doppler vision

Hello,
In issue 44 of How It Works there was a piece on the Doppler effect. Interestingly, I saw another article on how the Doppler effect could be used to produce invisibility cloaks. I will share what the article said since many of you will have heard about invisibility cloaks from *Harry Potter* and might be interested in theories about how to make things invisible.

The researchers were able to create it using an artificial nano-structured crystal from silicon and laser beams. By changing the distance between the cloak and the detector, they were able to create an inverse Doppler effect. I really liked your explanation of this phenomenon and the helpful graphic too. Have a nice day,
Raiyan

What’s happening on… Twitter?

We love to hear from **How It Works**’ dedicated readers and followers, with all of your queries about the magazine and the world of science, plus any topics you would like to see explained. Here we select a few of the tweets that caught our eye over the last month.

Vanessa @AspieMum
Having no tonsils when my kids get tonsillitis, I sometimes get laryngitis

Tania Strongman @taniastrongman
@HowItWorksmag
How long does it take a baby to open its eyes after being born?

Lee @Lee_1609
@HowItWorksmag
I’m 15 and currently studying Chemistry, Biology & Physics for my GCSE – I’ve got to say that **HIW** has helped me so much!

Myers Heir @Beeza68
The power of subscription. Delivered to my door. One of the two best reads of the month **@HowItWorksmag @spaceanswers**

All About Space @spaceanswers
@Beeza68 @HowItWorksmag
We’ll presume we’re number one… :-)

Myers Heir @Beeza68
@HowItWorksmag @spaceanswers
Sibling rivalry. You’re both brilliant reads. First subscriptions I’ve ever had. That says a lot!

Ryan @foppyish
@HowItWorksmag This definitely needed an explanation: Naked mole rats explained

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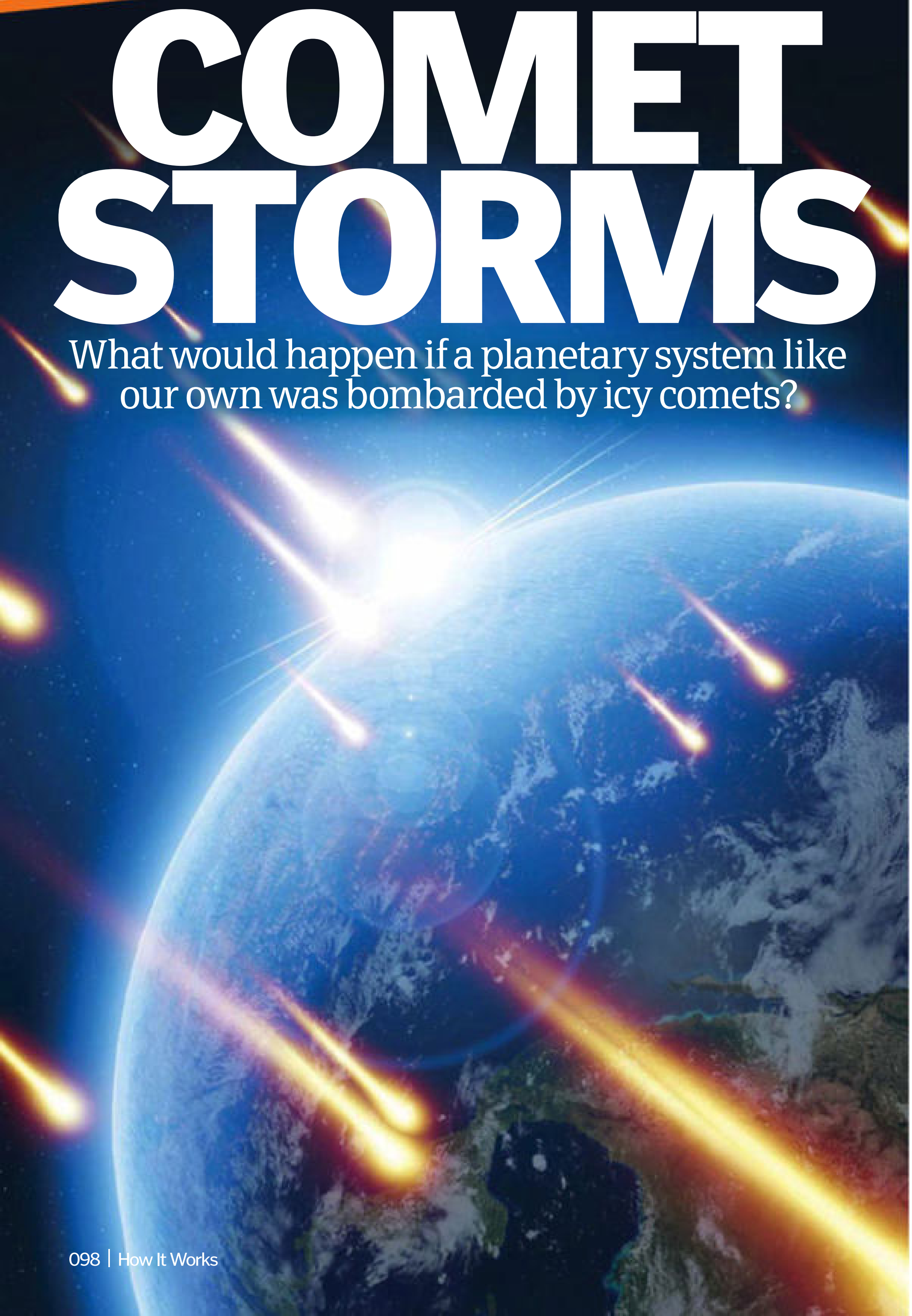

COMET STORMS

What would happen if a planetary system like our own was bombarded by icy comets?

ANSWERED NEXT ISSUE

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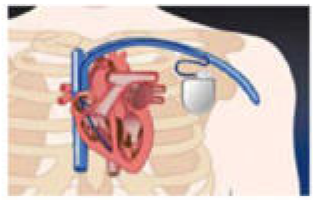
Why is the supermoon larger than usual?



How do pacemakers regulate heart function?

How does fossilisation turn bone into rock?

What unique anatomy do domestic pigs have?

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